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Dried Whey as an Additive for Alfalfa Haylage and as a Grain Supplement for Dairy Cows

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DRIED WHEY AS AN ADDITIVE FOR ALFALFA HAYLAGE AND AS A GRAIN SUPPLEMENT FOR DAIRY COWS

BY

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Doctor of Philosophy, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor Date

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Abstract

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Under the supervision of Professor Howard H. Voelker

This research was conducted to explore the possibility of utilizing surplus whey in dairy cattle rations. Four experiments determined the influence of whey on preservation, digestibility and feeding value of alfalfa haylage. The last experiment was initiated to evaluate dried whey as a grain supplement.

When dried whole whey was added at 0, 1, and 10% levels to reconstituted alfalfa haylage (chopped baled hay plus 50% water) and preserved in sealed metal containers, it reduced pH, decreased acetic acid, and increased lactic acid. The general pattern of fermentation was better in whey-treated haylages than in corresponding untreated haylages. An in vivo digestion trial using four Holstein steers, indicated that the whey-treated haylages had higher digestibilities of all chemical constituents analyzed except protein than did the untreated haylages. Correlation analyses suggested that the higher digestibilities were not due to the lower intakes of corresponding chemical constituents.

Hay was also compared with reconstituted whey-treated haylage. The haylage was preserved with 1% dried whey. A feeding trial conducted with 20 Holstein cows for 15 weeks in a double reversal design showed similar dry matter consumption from hay and haylage. Average daily body weight gains for cows were .40 kg for haylage and .15 kg for hay which

were significantly different ($P<.01$). Milk and fat production as well as persistency of production on hay and haylage were not significantly different. When 24 heifers were fed these forages for 3 months, average daily gains on haylage were 1.00 kg, on hay .81 kg ($P<.05$), while dry matter intakes from both forages were similar. In vitro dry matter and cellulose digestibilities of haylage were significantly higher than those of hay.

In another experiment, untreated haylages or haylages treated with 2% dried whey were fed ad libitum to 10 Holstein cows each for a 12-week continuous trial. The cows received concentrates at 1 kg/2.55 kg milk yield. Milk production and composition were similar for both treatment groups. Cows fed whey-treated haylage had higher body weight gain ($P<.01$) than that for the cows fed untreated haylage. Rumen pH and volatile fatty acid (VFA) values revealed no significant differences due to treatment. Results of the digestion trial using four Holstein steers showed higher digestibilities of all chemical constituents except ether extract for whey-treated haylages than for the untreated haylages.

A comparison between dried whey and lactose as a haylage additive was also made. First cutting alfalfa at 60% dry matter was chopped, treated with 0 and 2% dried whey and preserved in oxygen-controlled silos. Materials from the same source and the same dry matter treated with 0, 1.4, and 7% lactose were also preserved in sealed metal containers. Treatment levels containing 0 and 1.4% lactose corresponded to the relative amounts of lactose in the dried whey used in this study. Treated haylages had lower pH and higher lactic acid contents than the untreated haylages. Acetic acid concentrations in all haylages were below 1%. Treated haylages had more digestible chemical constituents than the corresponding untreated haylages. Lactose and whey were comparable in improving the digestibilities of haylages. Hay (from the same source) had lower digestibility coefficients than the haylages. Digestibilities of chemical constituents were usually highest for 7% lactose haylage. Total VFA concentrations in rumen fluids of steers were lowest for hay and highest for 7% lactose haylage. Inconsistent treatment effects were noted on percentages of individual rumen VFA and acetate to propionate ratio.

Dried whey was evaluated as a grain supplement in a 13-week continuous lactation trial using 20 Holstein cows. The experimental diet contained 5% dried whole whey and had the same amount of crude protein as the control diet. Milk yields, persistency of milk production, milk fat, milk protein, and total solids percentages were not altered by whey supplementation. Dried whey at this level as a grain supplement was not found to be advantageous to cows in late lactation.

INTRODUCTION

About 10 million metric tons of fluid whey are produced in this country annually. With the increasing trend toward cheese production, there is every indication that the amount of whey available for processing will increase. About a third of this whey is now used in human foods and livestock feeds. If the industry is to recover the other two-thirds of the whey production, which is now going to waste, it will be necessary to increase the uses of whey in foods and feeds.

In the state of South Dakota, 19 cheese factories produce over 24,000 metric tons of cheese annually. Some 200,000 metric tons of whey resulting from these operations is either (a) dried for human food uses, (b) dried for animal feed, (c) used for livestock feeding in its original form, (d) condensed or delactosed, or (e) disposed of in manners that may well contribute to water pollution.

Increasing whey production increases the disposal problem. Dumping of whey into a disposal system as a waste is a loss to the world's food supply. With increasing concern about environmental quality and antipollution legislation, traditional methods of whey disposal can no longer be practiced, and permissible disposal methods will entail considerably more expense. Under this new situation, there is an ever-increasing interest and determination to assure development of profitable uses for whey.

Before whey was utilized in human food, it was fed as a liquid to hogs, poultry, and other farm animals (178). Now, feed markets represent, by far, the largest outlet for whey and whey products. Greater proportions of whey are now being used in dry form. It is used in calf and pig starters and boosters; grain mixes for dairy cows; dry, pelleted, or block poultry feeds; horse feeds; sheep pellets; whey containing pet dog foods; and special blends for other animals (179).

Alfalfa is low in fermentable sugar and high in protein, and thus may be difficult to preserve. This is especially true under unfavorable conditions of packing and air removal which may be found on many farm conditions. Whey is an available source of lactose which can readily be converted to lactic acid under conditions of oxygen controlled storage. Addition of whey to haylage may result in a more desirable fermentation and a more palatable feed.

Recent studies (81, 83) showed that addition of whey to restricted roughage rations of cows caused milk fat production to return toward normal. There is virtually no information concerning the effects of adding whey to normal dairy cattle rations on milk production and composition.

This research was initiated to explore the possibility of utilizing dried whey in haylages and grain mixes for dairy cattle.

Dried whey was evaluated as a preservative for alfalfa haylages and as a supplement for dairy cattle grain mixes. Dried whole whey and lactose were added at different levels to alfalfa haylages at ensiling. The effects of whey and whey components on alfalfa haylage fermentation, digestibility, and nutritive value were studied. A lactation trial was conducted to evaluate the commercial application of dried whole whey as a grain supplement for dairy cows.

REVIEW OF LITERATURE

Preservation of Alfalfa Silage

Ensiling is a means of preserving a feed by fermentation (122). This process may not increase the total value of a forage, but forage loses less nutrients when stored as silage than as hay (18). Many factors are involved in the successful making of a palatable silage of high nutritive value, such as composition of the forage at the time of harvest, moisture content of forage before ensiling, the activity of plant enzymes, oxidation before ensiling and presence of air in the silo, the type of microorganisms present and their development, the production of organic acids by these organisms, the attainment of proper acidity, and the losses of organic matter in one form or another (153). The quality of final product also rests on the moisture level, temperature during fermentation, the presence and type of additives, and mechanical devices and their efficiency. Because of many factors involved and their unpredictability, silage making is not yet under complete scientific control.

Under usual farm conditions the factors responsible for successful silage making are not always favorable. To overcome these problems and assure a desirable fermentation, additives have been used. The functions of silage additives have been elaborated by Olson et al. (122), and Owen (123). Additives have been incorporated with the forages at the time of ensiling for several purposes: (a) to increase fermentable carbohydrates and thus increase the final acid content, (b) to supplement the acids produced by fermentation with other mostly inorganic acids, (c) to overcome the natural buffering capacity and allow a favorable pH to be obtained rapidly, (d) to inoculate the silage with desirable microorganisms, (e) to introduce antibiotics to suppress undesirable microorganisms, (f) to control the direction of the fermentation with inorganic salts, and (g) to add compounds that suppress fermentation entirely. The object is to reduce or retard fermentation losses, decrease seepage of soluble nutrients, increase palatability, and enhance nutritive value of the silage to be fed (14,122,153).

In the ensiling process, the first essential step is to achieve and maintain anaerobic conditions, thereby inhibiting harmful activities of aerobic microorganisms and oxidative enzymes of plant material. The second step is to inhibit protein breakdown by clostridia under anaerobic conditions. Clostridial activity can be inhibited in silage by two methods. The most direct procedure is to reduce the moisture content of the crop(s) to be ensiled. If the moisture content is decreased to about 65% by wilting in the field, subsequent clostridial activity in silage is slight, as these bacteria are very sensitive to osmotic pressure and require very wet conditions for active proliferation (181). The second method is to allow an acidic fermentation to take place. Stimulation of lactic acid fermentation presents a ready means of controlling changes in the silo. Normally, the fresh crop has an extensive microflora, which is capable of lactic acid fermentation. The medium for proper development of micro-organisms already present is the factor likely to be absent (177).

A pH of about 4 is favorable for the development of lactic acid bacteria and is unfavorable for clostridia. The quantity of fermentable carbohydrates is often low in alfalfa for sufficient production of lactic acid (14,145,155,170). Higher minerals and protein in alfalfa oppose the reaching of the proper acidity too; the minerals may neutralize some of the lactic acid produced during fermentation (86,170,187), and the higher protein content may contribute to buffering action and thus reduce the effective-ness of acids produced (155,177). Under these circumstances, there is a need for more fermentable carbohydrates to produce more organic acids to reach the desired pH.

Acid-type silages have been more acceptable, favoring increased consumption by cattle (18). Attempts have been made to promote lactic acid fermentation by addition of readily fermentable carbohydrates to the ensiling material. Such materials include: molasses, ground cereal grains, absorbents such as corn-and-cob meal, beet, beet pulp, potatoes, citrus pulp, brewers' dried grains, and dried whey (14,18,122).

Factors associated with silage fermentation

The effects on fermentation of such factors as plant species, moisture content, and sugar content of the ensilage crop(s) appear to be variable or even not clearly understood. Untreated high-moisture legumes have often resulted in poor quality silage and the relatively low carbohydrate content of these hay crops has been offered as an explanation (36,177,189). Dry matter content and the composition of alfalfa in relation to silage fermentation will be reviewed.

Dry matter

It was earlier pointed out that a desirable silage fermentation is more likely to take place in material with a high dry matter (DM) content (55,156), but the material should be ensiled before it has wilted excessively (19,194).

Woodward and Shepherd (192) studied the effect of high vs. low moisture content on ensiled forages. Silages were made from grasses, legumes, and grass-legume mixtures. Of the 50 silages studied, 4 had objectionable odors. These were all alfalfa silages with moisture contents above 73.5%; one was treated with 3% of molasses. Reduction of moisture content eliminated the objectionable odor and increased consumption of dry matter by dairy cows for all 4 silages.

Archibald and Kuzmeski (7) reported that high-moisture silage is undesirable because of off odors and high content of volatile gases, which are associated with butyric acid and high pH. They felt that a good estimate of silage quality could be obtained by determining water content and pH.

Hayden et al. (74) reported a summary of 69 lots of hay-crop silage made over a 10-year period. Most of these silages had a relatively high dry matter content. However, of the 6 silages which were predominately alfalfa with dry matter contents of 22% or lower, 3 had pH values below 4.13 and 3 were above 5.24.

Shepherd (141), in reporting several experiments on methods of ensiling, presented data for 3 different untreated first-cutting alfalfa silages with pH values of 5.4, 4.0, and 4.3. Initial maturity for all of the forages was 1/10 to 1/4-bloom stage. Schieblich (138,139) carried out an extensive series of experiments on the effect of water content on ensilage processes. With both clover and alfalfa, he found that the maximum moisture content for good silage was 75%. Above this, butyric acid was always present. To obtain the best type of silage with alfalfa, a moisture content of 65% was necessary.

Zelter et al. (196) ensiled alfalfa with dry matter contents ranging from 19.9 to 39%. Although lactic acid was produced in the first month, it was degraded by Clostridium species to butyric acid in the unwilted material. Wilting to a DM content of 35% gave a satisfactory silage.

According to Sullivan (153), the primary purpose of wilting forages before ensiling is to concentrate the plant sap; a more concentrated solution of sugars and salts gives more favorable environment to the desirable lactic acid-forming bacteria than to others. Wilting is dependent on weather conditions and is prolonged only a few hours. Murdoch (117) described a rise in percentages of dry matter of an alfalfa-orchard grass mixture from 19.8 to 34.4 in 6.5 hours. This represents a loss of about 18% of the original water, a change sufficient to favor the subsequent production of lactic acid.

According to Dutch investigations (48), the favorable effect of a high DM content may be due to retardation of acetic acid and, in particular, butyric acid fermentation. This has been confirmed, also, by investigations which have shown that the development of C. tyrobutyricum is promoted by an excess of moisture (151). From the standpoint of feeding, silage with high DM content has an advantage in that animals that consume it tend also to consume more dry matter (63,133,170,171).

The advantages of wilting crops before ensiling them to a DM content of 30% or above have also been stressed by other workers (63,177,197). Apart from reducing or eliminating effluent losses, the reduction in moisture content discourages clostridial activity and produces a silage which is more acceptable to ruminant animals (68).

According to McDonald et al. (103), high DM silages have higher pH values and contain more sugar than silages from unwilted herbage. Studies on losses during fermentation of wilted crops gave variable results. The DM losses from wilted silages ranged from 6.7 to 10.4%. The residual amounts of sugars in wilted silages were directly related to the degree of wilting. Little fermentation occurred at 47% DM.

Wilson (188) conducted an experiment to ascertain the effect of wilting forage crops on their content of fermentable carbohydrates. Wilting did not cause an increase in the fermentable sugar of the forages. According to him, if silage made from wilted crops is more acidic than that made from unwilted crops, the higher acidity does not come from increased fermentable sugar as a result of wilting nor from respiratory products developed during the wilting period.

Zimmer (197) reported that increasing the DM content by wilting was useful in making good quality silages from alfalfa, clovers, and grasses. The DM intake from wilted silages by ruminant animals was higher than from unwilted silages. Reduction of microbial activity, which resulted in lower levels of organic acids, was found by many workers as the fundamental pattern of fermentation in low moisture materials (4, 180).

The DM and nutrient losses of wilted material are due to some seepage production (110), and formation of gases (197). Their experiments showed highly significant correlations between

DM content and CO_2 production or VFA and CO_2 production as well. Zimmer (197) found that a direct-cut material produced approximately 2200 l CO_2/100 kg DM/30 days; wilted material with 40% DM only 1200 l CO_2/100 kg DM/30 days. He concluded that DM content in the range of 40 to 45% was suitable to minimize fermentation losses. Best results from wilting can be obtained with proper technique in the field. It is known that field losses will increase with duration in the field (37,172). Apart from mechanical loss, which is specific due to the equipment used, respiration of sugars can become detrimental. Under adverse weather conditions, the substrate for bacteria can become badly altered (172).

The stability of wilted silage is probably due to the inhibiting effects of low water activity on growth of clostridia (182).

The water activity falls as the concentration of solutes increases due to the loss of water during wilting, and also, subsequently, when large molecules are broken down into smaller ones during fermentation (183). In very dry tissue the matrix may further reduce the water activity of the system (92). Hydrolytic processes which occur in silage, such as the hydrolysis of hemicellulose and protein, may be expected to occur in low-moisture material unless the removal of moisture in itself has imposed some limitation on these reactions (47). The extent of protein hydrolysis in wilted forages is minimum. A passage of nitrogen into protein residues, which occurs rapidly during wilting, does not proceed when the forage of low-moisture content is stored anaerobically (25).

In the United States, wilting has been the most widely practiced improvement over untreated, direct-cut hay crop silage. A moisture content of 65% was formerly considered as the lower limit for grass silage stored in conventional tower silos. However, recent experimental results support ensiling of hay crops wilted to 40-60% DM in air-tight silos (40,63,171,174).

Forage containing only 35-40% moisture was successfully ensiled in Italy by the Crema Process (137), in which air exclusion was aided by weighting the silage surface with 600-2,000 lb. per square yard. The advent of gas-tight silos has presented the possibility of storing forage having less than 65-70% moisture but without the inconveniences of the Crema Process.

Shepherd et al. (142) compared haylage (about 50% moisture content) to wilted silages (65-70% moisture content) in gas-tight silos. They reported that storage losses of DM were about 1% in the haylage and 6% in wilted silage. The problem of mold growth was noted in the haylage. A later report by Voelker (169) showed no loss from spoilage in haylage and a total weight loss of 2-7%. Weight loss is less than DM loss in the low-moisture silage because any water formed by fermentation or respiration will remain in the ensiled mass. The possibility of extremely low dry matter losses in relatively dry, well-sealed forages has also been reported by Briggs (28) using plastic bags, and Langston et al. (95) using miniature steel silos.

Shepherd et al. (142) reported that haylage had a higher pH and contained more residual sugar than wilted silage. This was interpreted as indicating a less active fermentation.

Woodward and Shepherd (192, 193) previously reported that a high pH in wilted silage presented no problem for animal consumption. The preservation efficiency and chemical quality of silage made from direct-cut and heavily wilted (haylage) alfalfa were compared by Gordon et al. (63). The silages were preserved in gas-tight steel silos. They reported 4% DM loss for haylage and 22-23% DM loss for high-moisture silage. Lactic acid was higher and acetic acid was lower for haylages than for direct-cut silages. Haylage surpassed high-moisture silage in feeding value and acceptibility. Banancic (11) ensiled alfalfa at 5 DM contents in the range of 19 to 60%. Undesired fermentation processes were inhibited when the DM content was more than 37%. Dry matter contents of less than 37% increased acetic and butyric acid in silage.

Roffler et al. (133) evaluated alfalfa-brome forages when stored as wilted silage (65% moisture), low-moisture silage (50% moisture), and hay. Forage preserved as hay was lower in protein, ether extract, and ash than that preserved as low moisture silage or wilted silage. Wilted silage contained the most carotene, and hay contained the least. Several other workers (67,119,175) reported that forage preserved as hay contains less protein than the same forage preserved as silage. Roffler et al. (133) reported that wilted silage had a greater total acid content than did low-moisture silage. Butyric acid was the predominant acid present in wilted silage, and lactic acid predominated in low-moisture silage.

A number of workers reported DM consumption from wilted silage to be lower than that from high-quality hay from same crops (69,78). Animal acceptance, milk production, and live-weight gains were highest on hay. Haylage surpassed high-moisture silage in these respects (63, 65, 93). Roffler et al. (133) reported higher DM consumption by cows from low-moisture silage than from wilted silage and hay. Cows fed low-moisture silage or hay gained more body weight than cows fed wilted silage. Low-moisture silage ranked first in supporting 4% fat-corrected-milk production, wilted silage ranked second, and hay last. Fat test of cows fed wilted silage was higher than that of cows fed low-moisture silage. Fat test of hay-fed cows was lowest.

The digestibility of DM in these two forms of the same crop was lower in the wilted silage (32), about equal (89), and inconsistent from year to year (133). Gordon et al. (63) reported higher digestibility co-efficients for barn-dried hay, lowest for haylages, and intermediate for direct-cut silages.

One of the problems that has arisen frequently in farm use of wilted silage is heat damage. When heat damage occurs in forages, the resultant dark-colored nitrogenous polymer accumulates in the lignin fraction of acid-detergent insoluble fiber (165). The mechanisms involved in heat damage of feeds are of the Maillard type (35). Mailliard reaction or nonenzymatic browning is the result of condensation of compounds (usually derived from the degradation of carbohydrates) containing carbonyl groups with amino groups of proteins, amino acids and other compounds to form a dark-colored polymer (79).

Heat damage of forages due to heavy wilting (25-55% moisture) has been reported by Hill and Noller (77), Browning (30), and Roffler et al. (133). A Minnesota survey indicated 27% of silages were heat damaged (127). Several workers (17,26,30,49,61,77,184) have shown that both apparent protein digestibility and animal performance were decreased when animals were fed heated forages. The occurrence of heat damage in silage has been reported with increased frequency as more forages are ensiled at lower moisture content (30,77,133). Recent investigations of Goering et al. (59) under various controlled conditions of time, moisture, temperature, and pH showed that heat damage took place at 60 C in a 24-hr. heating period. The greatest amount of heat damage took place when moisture ranged from 20 to 70%. Susceptibility of forages to heat damage appeared unrelated to species, nitrogen content or initial insoluble nitrogen content.

The importance of wilting for practical farm practice is, to some extent, controversial (27). It is quite clear that it will be an advantage to wilt a young forage crop that is going into the bottom of a silo if there is no time to allow it to heat up. If the wilting is carried out too far, the material will overheat and the digestibility will fall, and the silage will be less valuable as a result (176).

Proper wilting is dependent on favorable weather conditions. To ensure silage of high nutritive value, cutting must take place over a limited period of time, which may lead to difficulties in rainy weather conditions. Some farmers find it rather impractical to carry out cutting and hauling in several steps during wilting. Also, wilting may involve a risk of molding and high losses of nutrients (27).

When the wilted material is filled into the silo, oxygen depletion takes place in a few hours. The aerobic cellular respiration evolves heat, which raises the temperature of mass in the area where oxygen is present. If this temperature rise is great enough, it will promote the growth of less desirable microorganisms, loss of carotene, silage will be heat damaged, and protein digestibility will be reduced (27,59,153,174). Aerobic fermentation, whether cellular or microbial, represents a loss of energy. A moderate prolongation of wilting, in spite of the loss incurred, is net benefit in that the soluble substrates are made more compatible for later production of lactic acid.

Despite its drawbacks, wilting is to be recommended when weather and other circumstances are favorable. However, because wilted material accelerates heating, the modern tendency is to look on it as a means of checking all microbial changes in the silo, instead of relying upon rapid acidification of the mass. According to Watson and Smith (176), wilting cannot replace the use of molasses which stimulates the formation of lactic acid. Considering the silo structure, techniques and methods of filling and packing, they strongly recommended the use of a fermentable carbohydrate like molasses in addition to wilting for young leafy, protein-rich crops.

Composition

The great differences found between various materials in respect to their suitability for ensiling are largely due to variations in composition (13,27,84,85). Forage crops with high sugar and low protein contents are easy to ensile satisfactorily (177). A high protein content is considered unfavorable, as the breakdown of protein may produce nitrogenous compounds which neutralize lactic acid, increase pH and favor butyric acid production (13,64,86,177).

Alfalfa is a protein-rich crop. Its composition varies with maturity, soil conditions, environmental conditions, and cultural practices (13,92). The leaf is always richer in protein and lower in fiber than the stem. The nutritive value of crops falls appreciably as it matures (131,176).

Sugars are the most readily available substrate for silage fermentation. The total amount depends upon sugar losses due to respiration and effluent buffer capacity in fresh material and alteration in buffer capacity during fermentation (197). Analyses of many forage samples for sugar content by Wilson and Webb (189) led them to the conclusion that legumes, because of their lower sugar content, did not ensile as satisfactorily as nonlegumes. Non-leguminous forage plants at the pre-bloom or early-bloom stage contained approximately three times as much fermentable sugars as the legumes do.

The time of harvesting is another important factor. Total sugars including fructosans, are low in very young grasses, but tend to increase as the plant matures. In alfalfa, the sugar content (on dry matter basis) at pre-bloom stage is 3.10% which increases to 4.26% at bloom stage (189). However, Langston et al. (95) and Melvin (109) found that sugar contents were highest at prebloom stage of growth. Melvin (109) reported that the sugar content of alfalfa ranged from 4% to 8% and starch content was about 2.5%. Marked seasonal and diurnal variations in total sugar percentages were noticed. Starch showed a diurnal variation, but its concentration was not affected by season or maturity.

Recently several workers (80,98,131,144,145) reported the concentration of total nonstructural carbohydrates of legumes and grasses and its importance to silage preservation. Total nonstructural carbohydrate (TNC) content of alfalfa ranged from

6.0 to 8.5% (144). There are reports (131) showing higher concentrations of TNC in alfalfa.

The differences in the carbohydrate contents reported by several workers may be due to their methods of extraction of carbohydrates from legumes and grasses (143,144). The amount of TNC extracted from legumes by 2% H_2SO_4 was higher than those extracted by enzyme method and this higher TNC content may be due to simultaneous extraction of hemicellulose with other carbohydrate (131). Extraction of carbohydrates by hot and cold water may result in biased comparisons often reported for grasses and legumes. Free sugars are highly water-soluble, but the non-structural polysaccharides are differentially soluble in water (144). The nonstructural carbohydrates of grasses are water soluble, whereas starch in legumes is largely water insoluble (1,143). Smith (144), using a method that removes and measures the TNC including sugars, fructosan and starch, reported the TNC contents of legumes and grasses. Alfalfa had lower TNC than grasses of temperate origin. However, tropical origin grasses showed lower concentration of TNC like alfalfa.

The concentrations of various carbohydrates in crops vary diurnally, presumably in response to diurnal changes in light intensity, temperature, and other environmental factors. Archibald (6) reported a significant inverse relationship between sugar content and average air temperature, slightly significant correlation between sugar content and rainfall, but little or no correlation with exposure to bright sunshine. Van Soest (168) reported that light intensity has a positive effect on the water soluble carbohydrates and a negative effect on crude protein, ash and fiber components. High temperature not only decreases water soluble carbohydrates, but also increases lignin and cell-wall content, thus resulting in a decline in nutritive quality. The carbohydrate concentration in alfalfa is about 1% higher in the afternoon than that in early morning (109). Lowest concentration of sugar in alfalfa was at 6 A.M. and highest concentration at 12:00 noon has been reported (80,98). While water-soluble carbohydrates declined during afternoon hours, the acid soluble carbohydrates increased quite rapidly. Silages made from morning and afternoon cutting alfalfa indicated that a higher sugar content in afternoon harvested alfalfa has a definite advantage in producing higher lactic acid and reducing pH (109).

Heavy precipitation during the growth period may reduce the sugar content of herbage crops to about half of that under good weather conditions (153). Nitrogen fertilization may reduce forage carbohydrates from 12.6% to 6.5% (99). In general, the literature indicates that high concentrations of carbohydrates occur under conditions that limit growth and development of plants.

Sullivan (153) suggested that the point of maximum sugar content would be the ideal stage at which to harvest for silage.

An early harvest has the danger of producing wet silage of high protein content, and a late harvest may need additives to assure sufficient acid production. Melvin (109) and Wilson and Webb (189) reported a decline of sugar content with increasing maturity of alfalfa. Early bloom stage gives the greatest yield of total digestible nutrients and sugar, and may be the best time for harvesting of alfalfa for silage (109,176).

Besides having lower sugar content, alfalfa contains more protein and minerals. The protein breakdown products can buffer a large amount of acid produced and the minerals neutralize the lactic acid (86,153,181,187). The buffering capacity of alfalfa varies with season of growth, maturity (70) and time of day (109). Such differences can make legumes less suitable than grasses for silage and, for this reason, legumes need supplemental carbohydrates to produce enough organic acid to assure a desirable fermentation (13,181). Addition of fermentable carbohydrate at the rate of 1.5% of green weight of legume forage produces a good quality silage (189).

Smith (145) calculated sugar requirements for the satisfactory conservation of grass and legume crops and suggested a minimum of 6-7% (dry weight) fermentable carbohydrate (hexose) was essential to lower the pH value to 4.0. This calculation was based on an assumed efficiency of hexose fermentation by bacteria, the dissociation constant of the resulting acid, and an assumed buffering capacity.

Such assumptions are liable to error as they do not take into account the variety of microbial activity possible.

Higher concentration of TNC in alfalfa may not provide adequate substrate to the microflora for desired fermentation and successful silage preservation. The TNC contains about 65% starch (98), whose contribution to the lactic acid appears to be limited (109).

All the water soluble carbohydrates available in the crop may not be fermented. In the ensiling process, substantial amounts may be lost through aerobic microbial oxidation and plant respiration. Fermentable carbohydrates surviving aerobic metabolism are fermented by a variety of microorganisms, of which lactic acid bacteria are the most important. Under ideal conditions, lactic acid bacteria grow rapidly, discouraging the growth of clostridia and other unwanted types of bacteria. Lactic acid bacteria are of two types, homofermentative and heterofermentative. The homofermentative type of bacteria, under anaerobic conditions, can produce two moles of lactic acid per mole of glucose fermented; and the heterofermentative type can produce, anaerobically, one mole of lactic, one mole of CO_2, and one mole of ethanol per mole of glucose fermented (190). Under these circumstances, it is impossible to predict the final ratio of products of lactic acid fermentation because a mixed population always develops, and it is possible for 100% variation to occur in the amount of lactic acid produced under two apparently similar situations (181). Type of carbohydrate is also important for lactic acid fermentation (13,177,181). Prediction of fermentation products is complex, not only for the type of sugar, but also for the buffering power of the plant material (38,39,181).

The development of more organic acid in silages than that can be accounted for by the initial low sugar content of different forages has been observed (4,5,107). These workers have strongly suggested that hemicellulose and possibly cellulose (197) are utilized to form acid. Barnett (13) suggested that fructosan, in addition to the sugar, accounted for the increased organic acid content. Hardwood (72) ascribed the loss of cell wall material in inoculated silage to the action of lactobacilli. De Man (46) similarly reported that the contribution of cell wall substances to the formation of organic acids may be responsible for the higher acids in the silage than could have been formed from the sugars originally present in the ensiling crops. The analysis of individual carbohydrates by Anderson and Jackson (4) in silages indicated 5.3% loss of hemicellulose caused by ensiling process. McDonald et al. (104,105,106) found a mean hemicellulose loss of 31%, which indicated a considerable degree of hydrolysis of this fraction during ensilage. Studies carried out by Dewar et al. (47) indicated that hemicellulose breakdown could be caused by plant enzymatic activity and also by acid hydrolysis. In addition to enzymatic breakdown of hemicellulose to sugar, an appreciable amount of reducing sugars is also produced.

Lactic acid producing bacteria have been shown (96) to ferment pentosans and galactans, which are constituents of hemicelluloses in plants. Marked differences in composition of fresh material and the resulting silage indicate a loss of hemicellulose (65,66). Recent work of Goering et al. (57) confirms that cell walls contribute to the formation of organic acids. He combined carbon-14 labeled wheat plant cell walls with ground orchard-grass hay substrate and ensiled. Substantial carbon-14 activity was found in lactic and acetic acids. Eight percent of the labeled cell wall was hydrolyzed through bacterial mechanisms. There are other reports (13,197) of losses of ensiled cellulose and lignin, whose contribution to the fermentation of organic acid is suspected.

Whey as a silage preservative

Whey offers an economic source of lactose and other nutrients for incorporation into silage as a preserving agent. As a source of fermentable carbohydrate, it has been used either as the natural whey (liquid whey) or as dried whey. The objection to the use of liquid whey is that the ensiled crop is often made too wet, and the handling and transportation of liquid whey is very cumbersome, but dried whey is a valuable additive for producing high quality silage from protein-rich herbages (13,177). Generally, whey-treated silages showed desirable fermentation in terms of high lactic acid content, low acetic and butyric acid contents, low ammonia, and reduced pH. However, some doubt has been expressed concerning the effectiveness of whey as a silage preservative (13,108,123).

Nevens and Kuhlman (120) added dried whey powder to alfalfa silage at the rates of 1, 2, 3, 4, and 5% of green weight at the time of ensiling. In comparing whey with other preservatives like blackstrap cane feeding molasses, lactic acid starter, and Bulgarlac culture, they concluded that whey powder was a most effective preservative in increasing palatability and acidity. The water soluble acidity for whey-treated silages ranged from 5.44 to 7.07%, compared to 4.63% for untreated alfalfa silage.

Allen et al. (2) made a comparative study to evaluate the relative effectiveness of whey and other preservatives with and without lactobacilli inoculum. The dried whey was added to supply

1 kg of lactose per 100 kg of green leafy grass. Fresh liquid whey was added at the rate of 150 gallons per ton of fresh material. All treated silages were excellent in quality and had higher animal acceptibility than the untreated silages. Addition of whey, like molasses (2 kg/100 kg fresh material), resulted in a material high in lactic acid. Lactic acid, calculated as residual acidity, was 2.43% for whey-treated silages (26% DM). The pH value for whey-treated silage was 3.84. Fresh liquid whey produced similar results as did dried whey, but indicated a possible danger of adding too large a quantity of fluid along with mixed flora.

Johnson et al. (87) studied various methods of preserving legumes and other forages by ensiling.. He used dried whey at the rates of 1 and 4% and sour-whey concentrate at the rates of 3.5, 7, and 14% to freshly-cut alfalfa (24-35% DM) preserved in bottles. The pH values decreased with increased levels of whey in silage. Dried whey at 4% and sour-whey concentrate at 7 and 14% produced good quality silage. Some freshly-cut alfalfa (25 to 28% DM) treated with 2 and 4% dried whey were preserved in silos. The characteristics of silages in barrels and silos followed the same trend as bottle silages. On the basis of their results, the use of dried whey at the rates of 1.5-2% of fresh material was recommended.

Martin et al. (108) conducted experiments to estimate the relative values of dried whey and ground shelled corn as alfalfa silage preservatives. A comparison of wilted and unwilted alfalfa was included in this experiment. Dried whey was added at the rate of 1.5% of green material and ground shelled corn at the rate of 10% of green material before ensiling. The silages were emptied from silos after six weeks. Dried whey, when applied at this rate, had no significant effect on the amount of top spoilage, but ground shelled corn was more effective in reducing top spoilage. There was less top spoilage in unwilted silages than in the wilted silages. Neither moisture level nor application of preservative appreciably affected nutrient preservation in the unspoiled portion of the silage. Moisture levels, rather than preservatives, seemed to have the most consistent effects on total acidity, acetic acid, butyric acid, residual acidity and volatile base values. Little variation was found due to treatments; there was no correlation between pH and spoilage.

Stallcup (149) used third-cutting alfalfa (18% DM) for comparing silage preservatives. Treatments used were: no treatment, whey powder (2% of fresh material), molatein (4% of fresh material), Kylage old formula (.25% of fresh material), and Kylage new formula (.25% of fresh material). The dry matter loss was 4.5% for whey-treated silage, which was lowest among the treatments. Carotene preservation was best in the silage treated with whey. Whey-treated silage was most preferred by dairy heifers who consumed about 7 kg more per day than the heifers receiving untreated silage.

Salisbury et al. (136), working on the theory that the desired effect of silage preservation is acid production by lactic acid bacteria from carbohydrates, tested the preference of the bacterial population, as it exists in the silo, for the number of carbohydrates. They ranked the sugars in order of their fermentation qualities. Arabinose, glucose, sucrose, fructose, and xylose resulted in the production of more acid than other sugars tested. Galactose was eighth in rank and lactose ranked lowest.

Whey in Animal Feeding

Liquid whey feeding

Lynch et al. (102) and USDA workers (62) suggested that the use of liquid whey in animal feeding would help provide a market for whey without drying expenses and help eliminate a source of water pollution. Utilization of liquid whey by farm animals is not entirely a new idea. The major direct farm use has been by swine. When the dairy cows are near the milk processing plant, the possibility of recycling whey through the cows is suggested by the USDA workers.

A USDA study (62) of feeding sweet liquid whey to dry cows showed that the whey consumption was 25 to 30 kg/cow/day. Although cows had loose feces, their average weight gain was more than 1 kg/day and their general health condition was good. They were convinced that sweet whey could be fully substituted for water. They are now working to develop a whey distribution system to feed liquid whey to dairy cows.

Lynch et al. (102) conducted a calf trial to test the feed supplements combined with acid whey (AW). The supplements were: (a) 13% protein ration (NCF 1); (b) 60% protein soybean concentrate mixed with AW (1.1 kg/38.6 Kg AW) plus NCF 1 as a dry feed; (c) 49% protein soybean meal mixed with AW (1.4 kg/38.6 kg AW) plus NCF 1 as a dry feed; and (d) AW plus a 31% protein ration fed dry. The final body weights were (a) 118.2, (b) 135.9, (c) 145.4, and (d) 148.2 kg. Total feed conversions were (a) 3.59, (b) 4.35, (c) 3.71, and (d) 3.14 kg DM/kg gain. Ration (a) produced significantly ($P < .05$) lower final body weights than (b) and significantly ($P < .01$) lower body weights than (c) or (d). Growth responses indicated that acid whey may constitute up to 31% of dry matter of calf ration if supplemented with high protein. Accumulation of flies and bloat were the management problems associated with sweet and acid whey feeding (62). At Kansas Station, Morrill (113) tested various levels of sweet dried whey, partially delactosed whey, and partially demineralized whey in calf starters. Levels as high as 40% dried whey were successfully used. The effect of feeding whey on rumen development was being studied.

Whey as milk replacer

Lactose is the preferred carbohydrate of young calves and pigs. Dried whey, which contains about 70% lactose, is not only the most readily available and most economical source of lactose, but it also provides some excellent quality protein.

As a result, baby pig and calf formulas have, today, become the major animal feed markets for dried whey (121). Morrill et al. (114) evaluated a soybean protein concentrate as a protein supplement for milk replacers high in whey. Three milk replacers that they compared contained 59.2, 67.9 and 76.6% sweet dried whey. Their results indicated that good quality dried whey can make up at least 67.9% of milk replacer formula. At 76.6% level of dried whey, no adverse effects were observed other than a reduced rate of gain.

Michigan State workers (97) conducted experiments to determine the protein requirements of calves during the milk replacer feeding period, and level of dried whey that can be used satisfactorily in milk replacers. Protein levels of about 12, 16, 24, and 30% were fed. To reduce protein content, dried whey and glucose were substituted for dried skim milk. The lowest protein diet contained 52% dried whey. While inadequate protein reduced growth performance on this diet, no adverse effects of diarrhea were found with the 52% level of dried whey. Solms (147) reported that acid whey can be used in milk replacers, provided it does not exceed 15% of the formula.

This research data, along with commercial usage, have demonstrated that good quality dried whey can be used extensively in calf replacers, provided there is adequate supplementation of protein to meet the dietary requirements of the calf. Many of the differences reported in literature may be due to differences in quality of the whey products used.

Hedde and Ward (75) made a comparative study of whey and milk replacer as feeds in a rumen by-pass system of feeding calves. Calves receiving 35% of intake as whey and a 11% protein ration showed a 30% greater average daily gain and an 8% better feed efficiency over meat-fed calves receiving total 17% ration protein. Calves fed liquid milk replacer and receiving 15% total protein had a 21% greater average daily gain and 31% better feed efficiency than the calves receiving the dry milk replacer with the same amount of dietary protein.

The use of whey protein concentrates as an additive to whole milk rations for calves is being studied at South Dakota (115). The possibility of such a supplemental value has been suggested by Owen et al. (124), who showed a large calf response from feeding colostrum milk, which is also high in whey protein.

Luther (101) initiated a study using sheep to determine the effect of adding whey, lactose, and glucose or of heating the ration on volatile fatty acid concentrations in the rumen. The results indicated higher feed efficiency for whey-supplemented rations. Ten percent whey in the ration did not alter the rumen pH, but lowered rumen acetate, increased propionate, and narrowed the acetate to propionate ratio.

Whey for beef cattle

Woods and Burrough (191) conducted feeding trials with beef steers to determine the value of added whey and lactose in growing and fattening rations. Addition of .23 kg whey per animal per day increased gains by .1 kg per day. Substituting the equivalent amount of lactose as contained in .23 kg whey did not increase gains to the same extent as whey, suggesting that whey protein and minerals have beneficial effects on animal performance. Feed efficiency improved with whey supplementation. Whey addition to both fattening and growing rations was beneficial in increasing animal performance. Higher rumen propionate due to whey addition may possibly be the cause of increasing animal performance.

Dried whey for dairy cows

High-concentrate and low-fiber rations usually cause milk fat depression in dairy cows. The usefulness of lactose in increasing milk fat production in high concentrate rations has been reported by Bowman and Huber (24). Huber et al. (81)

selected whey to conduct further investigations of lactose effects on milk composition and rumen fermentation because of its high lactose content. They fed 16% hay and 84% concentrate to lactating Holstein cows. Concentrates contained varying amounts of partially delactosed whey and dried whole whey. The percent of fat in milk was maintained at pretreatment levels when as little as 10% partially delactosed whey was incorporated into the concentrate. Dried whole whey at the 30% level was not as effective in maintaining milk fat as partially delactosed whey. Neither milk solids-not-fat nor protein was consistently affected by addition of whey. Milk production was depressed when the concentrate contained 60% of either whey, but not 30%.

Addition of both kinds of whey resulted in a significant increase in concentrations of rumen butyrate. These increases were probably due to lactose in whey. Rumen propionate was decreased and acetate-to-propionate ratios increased by addition of partially delactosed whey, but not of dried whole whey.

In another lactation study, Huber et al. (83) fed concentrate ad libitum and 2.3 kg hay/day to Holstein cows. Concentrates contained varying levels of whey (0, 3.7, and 14%), or minerals (2.5% NaH CO_3 and 1% mg O), or both whey (14%) and minerals. Fat depression was least on the mineral rations, but concentrate intake and milk yields were also lowest. As whey in concentrate increased, milk fat also increased, with 14% whey almost as effective as minerals.

Compared to controls, rumen pH was increased by minerals but not by whey. Both minerals and whey decreased rumen propionate and increased acetate; whereas, butyrate was increased only at 14% whey. According to these workers, the stimulation of milk fat synthesis by whey and minerals was mediated, not by a metabolic reversion of conditions found on a normal ration adequate in forage, but rather through increased mammary uptake of fatty acids from serum lipoprotein. Thus, while the fat percent was returned towards normal, the composition of this milk fat was still more unsaturated than normal.

Experiments were conducted at South Dakota (140) to determine which component(s) in whey were most responsible for preventing milk fat depression when whey was fed in high concentrate rations. When Holstein cows were switched from a normal ration (alfalfa hay, corn silage, and concentrate mix) to one of a restricted hay and control concentrates ad libitum, milk fat content was depressed by 1.16% as expected. When the concentrate included either 14% dried whole whey or 5.9% high mineral whey products, milk fat content was depressed by only .5 and .4%, respectively. Concentrates containing 11.8% demineralized whey caused milk fat depression by 1.16%, suggesting that whey minerals were most effective in preventing milk fat depression on high-concentrate rations. The milk fat depression from the ration containing 9.8% lactose was, however, comparable to that of 14% dried whey and 5.9% high mineral whey treatments. Rumen butyrate was higher and propionate was lower on rations containing whey products than on the control rations.

In conjunction with these experiments by Schingoethe et al. (140), the fatty acid composition, phospholipid content of milk fat (125), as well as the flavor (126) of the milk produced by these cows were also evaluated. Addition of whey products to a high-grain ration caused the milk fat produced to contain less palmitoleic and oleic acids, with stearic and linolenic acids variable depending on the type of whey product used in the ration. The phospholipid content of milk fat increased on all rations during the trial. Linoleic acid increased in the phospholipid fraction while stearic and oleic acids decreased.

Evaluation of flavor of milk samples indicated that during standardization, all milk samples had none or questionable oxidized flavor, and milk samples from the experimental period showed the same flavor characteristics when fresh, but all samples showed an increased intensity of oxidized flavor on storage. According to Parsons et al. (126), the incidence of oxidized flavor may be related to high-grain, limited-roughage rations in general and not to specific whey-treated rations.

Dried whey in normal dairy cattle rations

California workers (21) conducted an experiment with lactating dairy cows to test the effect of dried whey in a normal ration on milk and fat production. Dried whey product was incorporated in pelleted concentrates at a 5% level, which was 3.7% of the total concentrate mix. Under their experimental conditions, dried whey appeared to cause a slight increase in milk fat percentages, but this was offset by a 1.5% decline in production of 4%, fat-corrected milk. Cows fed the dried, whey-product ration consumed .23 kg/day more concentrate than the control cows.

Experiment No. 1

INFLUENCE OF DRIED WHEY ON ALFALFA HAYLAGE PERSERVATION AND DIGESTIBILITY

Introduction

The most important points in silage making are the need for a fermentable carbohydrate as a source of lactic acid and viable lactic acid organisms with high capacity to withstand high concentrations of acid (13,155,177). Fresh plant materials contain in general a sufficient microflora of lactic acid bacteria, but also contain putrifactive and butyric acid bacteria. When the ensiled material contains enough sugar and is stored anaerobically, the lactic acid bacteria multiply rapidly, and the lactic acid formed preserves the silage (2,64,151).

It is recognized that the differences in the protein and sugar content of the forage before ensiling are responsible for much of the variability in the silage produced (54,64,70). The amount of carbohydrate is often low in alfalfa and, in addition, these plant materials contain high protein and calcium contents which neutralize the lactic acid produced (189).

Zelter (196), adding 1, 2, or 3% of glucose to alfalfa, raised the water soluble carbohydrate (WSC) content to 8.9, 12.6, and 16.6%, respectively. Satisfactory preservation only occurred if the WSC concentration of the medium reach 12.6 - 16.1%. This relatively high level of WSC is necessary to overcome the high buffering capacity of alfalfa (36, 105). Early studies of Nevens and Kuhlman (120) and Allen et al. (2) suggest that whey can be successfully used as a preservative for alfalfa silage.

Preliminary work at this station (45) indicates that whey is an effective haylage additive. When dried whey was added to alfalfa haylage it reduced pH, increased lactic acid, and decreased mold growth. Intake data indicated that whey-treated haylages were more acceptable by dairy calves than untreated haylages or hay.

Considering the importance of an adequate supply of fermentable carbohydrate for alfalfa for producing silage of high quality, dried whey was selected as an additive for the present study. This experiment was designed to determine the effects of dried whey on alfalfa haylage preservation and digestibility.

Experimental Procedures:

A study was conducted to determine the influence of dried whole whey on alfalfa haylage fermentation and in vivo digestibility. In order to be consistent with the previous work, reconstituted alfalfa haylages were used. First cutting alfalfa hay was chopped with a forage harvester set at about 1 cm chop length. Water was added to the chopped hay to make approximately 50% moisture level. The forages were then ensiled with 0, 1, and

10% dried whole whey on dry matter basis in air tight metal containers for one month before the onset of the digestion trial.

After a 3-week adjustment period 4 Holstein steers weighing about 180 kg were fed the experimental haylages in a 5-day total collection period digestional trial as recommended by Hattan and Owen (73). Daily feed intakes and feces outputs were weighed and sampled. Duplicate samples of feed and feces from the steers were dried (48C for 48 hr) using a forced air oven and chemically analyzed for crude protein by Kjeldahl procedure, ether extract and ash by the AOAC methods (8); cell wall (neutral detergent fiber), ADF (acid-detergent fiber), lignin and cellulose by the Van Soest system of fiber analyses (58). Hemicellulose contents of the feed and feces were the differences between cell walls and acid detergent fiber (58). Energy values were determined by using a Parr Oxygen adiabatic bomb calorimeter.

Reconstituted alfalfa haylages were sampled daily for 5 days during the collection periods of the digestion trial. The pH values of the haylages were determined according to Barnett (13). Haylage extracts treated with 25% metaphosphoric acid were analyzed for volatile fatty acids by gas-liquid chromatography using the procedure of Baumgardt (15). Haylage extracts for lactic acid determination were prepared by the following procedure: In an air-tight one pint mason jar, 100g of haylage was mixed with 60 ml of distilled water by thorough shaking, The jar was kept in a refrigerator for 24 hours. The material was pressed by a Carver Laboratory Press[a] to obtain the extract. The extract was deproteinized by the methods of Rumsey (134) and lactic acid was determined following the procedure of Langlois (94).

The data were subjected to analysis of variance by the procedures of Steel and Torrie (150). Significance between treatment means was tested by Duncan's multiple range test (50). Correlation analyses (150) were conducted between the intakes and digestibilities of the chemical constituents of haylages to see if these were related.

Results and Discussion

The pH values decreased significantly ($P<.01$) with increased levels of whey in the haylages (Table 1). Lactic acid contents (Table 1) significantly increased ($P<.05$) in haylages treated with whey. Although 10% whey-treated haylage appeared to have higher lactic acid content than 1% whey-treated haylage, this increase was not significantly different ($P<.05$). Acetic acid concentrations in the haylages followed a reverse trend. It decreased with increased levels of whey in the haylages. In general, the fermentation pattern in alfalfa haylages indicated that dried whey was effective in stimulating lactic acid production, decreasing acetic acid production and reducing the pH. The quality of the whey-treated haylages was considered good for their

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[a]Fred S. Carver, Inc., Summit, New Jersey.

higher lactic acid contents, lower pH values and for the absence of butyric acid production (38, 95).

The pH values were lower in whey-treated haylages which agreed with the pH values reported by Allen et al. (2), Neven and Kuhlman (120) and Dash and Voelker (45). The decreases in the pH values were not proportionate to the levels of whey in the haylages. This supports the observation of Melvin (109) who reported that silage pH was not perfectly related to the sugar content. Furthermore, pH is not always a reliable index of acid production or silage quality (36, 38). High dry matter silages tend to have higher pH values (36, 103). The haylages prepared for this experiment had about 50% dry matter, but addition of whey resulted in desirable fermentation and reduced pH. A similar observation for wilted silages has been made by Anderson and Jackson (4).

The chemical constituents including fiber fractions of the reconstituted haylages are presented in Table 2. The crude protein and ash content did not change in the reconstituted haylages also. Ether extract contents were slightly higher in whey-treated haylages. Energy values of 0, 1, and 10% whey-treated haylages were similar. Cell wall, ADF, cellulose, and hemicellulose contents decreased with addition of whey in the haylages. Lignin content was not different due to whey treatment. A few samples tested for ADF in soluble nitrogen did not indicate the signs of heat damage effects on any haylage.

The reduction of cell wall components particularly of hemicellulose and cellulose suggested that these fractions were partially utilized in the haylage fermentation process or that the lower contents of cellulose and hemicellulose in whey-treated haylages may be due to higher levels of whey in the haylages. McDonald et al. (104, 105, 106) reported a mean loss of 31% of hemicelluloses from silages during fermentation. De Man (46) and Zimmer (197) reported the possible contribution of cell wall constituents to the formation of organic acids in the silage.

The results and statistical analyses of the digestion trial are presented in Table 3. Apparent digestibilities of dry matter, ether extract, energy, ash, cell wall, ADF, lignin, cellulose and hemicellulose were increased in haylages treated with whey. Higher digestibilities were found generally for 10% whey treated haylages, except cellulose digestibility was highest for 1% whey. This lower cellulose digestibility in 10% whey-treated haylages was compensated by the significantly higher lignin and hemicellulose digestibilities. The basic alterations in fermentation produced by addition of soluble carbohydrate might be responsible for the increased digestibility, which was in agreement with the work reported by Allen et al. (2). They reported higher digestibilities of ether extract, fiber and protein for whey-treated grass silages than those for untreated silages.

The digestibility of protein was not influenced by whey treatment. Dry matter, energy, ether extract and even ash appeared to be more digestible from whey-treated haylages than those from untreated haylages. The in vivo digestibility data were closely related to the in vitro digestibility data of the preliminary study (45).

Correlation analyses of intakes versus digestibilities indicated that the higher digestibilities obtained for the chemical constituents of the whey-treated haylages are not due to the lower intakes of these constituents.

TABLE 1. Chemical quality of alfalfa haylages fed to dairy steers.

Items	0% Whey haylage	1% Whey haylage	10% Whey haylage	Standard error
pH	5.30 A	4.68aB	4.30 bB	± .12
Lactic acid (%,DM)	6.24 a	11.62 b	13.02 b	±1.60
Acetic acid (%,DM)	1.33 A	1.28 A	.77 B	± .05

For a given trait, treatment means not sharing a common letter are significantly different, lower case ($P<.05$), upper case ($P<.01$).

Lignin in forage plants is frequently assumed to be completely indigestible by ruminants (153, 173) although many examples to the contrary exist in the literature (60, 111, 116, 133, 160). There are differences in lignins. Towers and Gibbs (163) and Stafford (148) have shown that histochemical and biochemical differences

TABLE 2. Average composition of alfalfa haylages fed to dairy steers.

Items	0% Whey haylage	1% Whey haylage	10% Whey haylage
Dry matter (%)	40.9	44.9	50.9
Energy[a] (K cal/g)	4.20	4.24	4.18
Crude protein[a] (%)	19.5	19.7	19.2
Ether extract[a] (%)	2.84	3.44	3.02
Ash[a] (%)	8.8	8.6	8.8
Cell wall[a] (%)	50.8	49.8	43.2
Acid-detergent fiber[a] (%)	37.4	35.9	31.4
Lignin[a] (%)	8.4	9.2	8.6
Cellulose[a] (%)	27.6	24.8	21.2
Hemicellulose[a] (%)	13.4	13.9	11.7

[a]Dry matter basis.

TABLE 3. Digestibility of alfalfa haylages fed to dairy steers.

	0% Whey haylage	1% Whey haylage	10% Whey haylage	Standard error
	Digestion coefficients			
Dry matter	53.7aA	58.9bA	65.8B	±1.18
Energy	52.9aA	57.8bA	64.4B	±1.19
Crude protein	65.3	65.8	67.6	±1.01
Ether extract	47.6A	61.2B	64.3B	±1.07
Ash	41.1A	45.9AB	52.8B	±1.99
Cell wall	53.7A	57.1AB	62.2B	±1.50
Acid-detergent fiber	50.5a	54.7ab	57.2b	±1.74
Lignin	14.6aA	27.4bA	39.2B	±2.79
Cellulose	59.7aA	68.2B	65.7bB	±1.33
Hemicellulose	62.7A	65.9A	76.0B	±1.84

For a given trait, treatment means not sharing a common letter are significantly different, lower case ($P < .05$), upper case ($P < .01$).

exist in the lignins of the stem internodes, the leaf sheath and the leaf lamina of forage plants. This, together with the known chemical difference that exists between forage and fecal lignin (52) adds to the difficulty of interpreting the results of chemical analyses of lignin in terms of digestibility. Moreover, despite the constant occurrence of nitrogen in lignin isolated by commonly used methods (153), it is not always clear whether some researchers have measured this amount of impurity. Recently Gordon and Homes (60) described lignin in two different fractions, core lignin and noncore lignin. Core lignin consists of phenolic monomers linked mainly by ether and carbon to carbon bonds, while noncore lignin consists mainly of ferulic and P-coumaric acids linked to core lignin by ester bonds. These bonds are easily broken by alkali and may also be hydrolysed in the digestive tract in which case some digestion of lignin would occur. Muller et al. (116), Waite et al. (173), Thomas et al. (160) and Allison and Osbourn (3) have reported up to 42% digestibility of lignin in forage plants. In the present trial higher lignin digestibility in whey treated haylages was possible probably in accord with the above theory.

Improved digestibilities for cellulose, hemicellulose, lignin, cell wall, and ADF in whey-treated haylages could be partially explained in light of the results reported by other workers (88, 90, 91) who obtained higher digestibilities of fiber components by improving lactic acid fermentation in the silage.

Generally, the higher digestibilities for most of the chemical constituents in whey-treated haylages may be attributed to their improved fermentation.

Experiment No. 2

COMPARISON OF RECONSTITUTED WHEY-TREATED ALFALFA-BROME HAYLAGE AND HAY

Introduction

Under conditions where dairy farms are mechanized for handling haylage, there may be interest in making hay into reconstituted haylage. Baled hay is not easily fed mechanically and is not as completely consumed as haylage. If dairy cattle are used to haylage and the regular haylage supply is limited, as it happens in spring, there may be some merit in stretching the haylage supply until the new crop is available.

Some studies (31, 33, 51, 76, 133, 160) have indicated that haylage is equal or superior to hay. Gordon et al. (63) compared direct-cut silage and haylage with barn-dried hay. Dry matter (DM) intake was improved with haylage (39 to 53% DM) compared with direct-cut silage (24 to 27% DM), but haylage did not improve milk production. Differences in digestibility of dry matter between direct-cut silage or haylage and hay have been inconsistent and show year-to-year variations (63, 118, 159, 160). Animal performance data have not shown a definite advantage for either direct-cut silage, haylage or hay (160, 161, 164). Heifer feeding trials of short term duration have given conflicting results (128, 161). It appeared desirable to perform additional short term studies to determine relative feeding values of haylage and hay.

Whey is an effective silage preservative and may produce good quality silage or haylage (120, 177). The present study was undertaken to determine the relative feeding values of reconstituted whey-treated alfalfa-brome haylage and hay, and to obtain specific information on the feasibility and desirability of making whey-treated haylage with dried whey and water. Comparison between reconstituted haylages with and without whey was not possible due to the unavailability of silo storage. Such comparison will be made in later studies.

Experimental Procedure

Third-cutting alfalfa-brome baled hay containing approximately 70% alfalfa and 30% brome, was chopped with a forage harvester set at about 1 cm. chop length. Water was added to the chopped hay to make 35% moisture level. Dried whole whey was added at 1% of dry matter. The material was mixed and stored in an air-free silo for more than four weeks prior to feeding. The same kind of hay was reserved for the present trial.

Twenty lactating Holstein cows were assigned to two treatment groups balanced on the basis of milk production, fat percentage, and stage of lactation. The lactation trial was conducted using these 20 cows for 15 weeks in a double reversal design using the haylage and hay as the single forage. A three week adjustment period was used.

The same concentrate mix that had been fed regularly to these cows prior to the trial was fed at the rate of 1 kg per 3 kg milk. The amounts fed were readjusted each week based on previous weeks' production. The forages were fed ad libitum. The percent composition of the concentrate mix is given in Table 1 and the average chemical analyses of the concentrate mix and forages are in Table 2. Weekly core samples of hay, grab samples of silage and concentrate mix were taken for chemical analyses (Table 2). All analyses were done by AOAC Methods (8) except for fiber components which were analysed by Van Soest procedures and cellulose by Crampton and Maynard procedure (44). Organic acids and pH of the silage samples were determined by the procedures of Barker and Summerson (12) as modified by Barnett (13). Daily feed consumption and milk production data of all cows were recorded. Daily composite milk samples were taken on alternate weeks and analysed for milk fat by AOAC methods (8). All cows were weighed on three consecutive days at the beginning of the experiment, then once every week, and three consecutive days at the end of the lactation trial. All the data were statistically analyzed by the procedures of Snedecor and Cochran (146).

Four composite samples from hay and four others from haylage were subjected to in vitro dry matter and cellulose digestibilities (162). Due to the limited number of observations of the in vitro study, the data were not subjected to statistical analyses.

In another trial, 24 3-month old Holstein heifers, 12 in each treatment, were used to determine the growth response from hay and whey-treated haylage. The same hay and haylage, that were used in

TABLE 1. Percentage composition of concentrate mix.

	(%)
Rolled shelled corn	51.25
Oats	34.00
Soybean (50% CP)	11.25
Urea	1.00
Dicalcium phosphate	1.25
Trace mineral salt	1.25

The concentrate mix contained 4,400 IU Vitamin A/kg and 600 IU Vitamin D/kg.

the lactation trial, were fed ad libitum for 12 weeks and the grain mix was fed at the rate of 1.36 kg per head per day. Feed sampling and analyses were done along with the lactation trial. Body weights were taken twice monthly. The data were analyzed by analysis of variance procedures as described by Steel and Torrie (150).

Results and Discussion

Table 2 shows the average dry matter content and proximate dry matter composition of the concentrate mix, hay and whey-treated haylage. The dry matter composition of hay was similar to haylage at ensiling. However, there was a slight advantage in terms of more protein and less fiber for reconstituted haylage. Methods of harvest and storage influence the composition of forage (63, 133, 160). Several workers (63, 119, 133, 175) have previously reported

TABLE 2. Average chemical analyses of concentrate mix and roughages fed.

	Concentrate mix	Hay	Haylage
Dry matter (%)	90.0	85.0	65.0
Crude protein (%, DM)	16.8	16.4	17.4
Ether extract (%, DM)	3.9	1.7	1.7
Ash (%, DM)	3.7	8.6	9.1
Nitrogen-free extract (%, DM)	68.8	41.2	40.2
Crude fiber (%, DM)	6.8	32.2	31.5
Acid-detergent fiber (%, DM)	---	36.7	34.5
Permanganate lignin (%, DM)	---	9.3	9.0
Cellulose (%, DM)	---	25.9	22.7
Hemicellulose (%, DM)	---	10.4	9.7
Cell walls (%, DM)	---	47.1	44.2
pH	---	---	4.4
Lactic acid (%, DM)	---	---	6.0
Acetic acid (%, DM)	---	---	0.7

that forage preserved as hay contains less protein than the same forage preserved as silage. Incorporation of 1% dried whey might not have contributed to the higher protein percentage of haylage as such, as it contained less protein than the forage. The higher protein content with subsequent reduction of fiber content was an indication of improved fermentation. It seemed probable that there was less breakdown of protein and some utilization of cell wall components in the fermentation process.

Chemical quality of the whey-treated haylage was evaluated on the basis of pH, lactic acid and acetic acid content (Table 2). The pH was 4.4, which was considered low for 65% dry matter haylage. Lactic acid concentration in the haylage was 6.0, which was comparatively high for alfalfa haylage. It was assumed on the basis of previous work reported earlier in the thesis that whey stimulated lactic acid production. Lower level of acetic acid, absence of butyric acid, high content of lactic acid, and reduced pH indicated that the haylage was of good quality.

Results shown in Table 3 indicate that cows in both treatment groups consumed equal amounts of forage, grain, and total dry matter. When dry matter intake was calculated on the basis of percentage of body weight, forage, grain or total dry matter intakes were similar for both groups. Milk production data (Table 3) did not show any difference due to haylage feeding. When milk yield was converted to 4% fat-correct (FCM) milk no difference between

TABLE 3. Response of cows fed hay and haylage.

Response	Group: Haylage	Hay
Dry matter intake (kg/day)		
forage	10.6	10.4
Concentrate	9.0	9.0
Total	19.6	19.4
Dry matter intake (% of body weight)		
Forage	1.58	1.56
Concentrate	1.34	1.35
Total	2.92	2.91
Milk production (kg/day)		
Actual milk	23.5	23.3
4% Fat-correct milk	21.2	21.5
Persistency of milk production (%)[a]	93.8	92.8
Milk fat (%)	3.1	3.2
Body weight (kg)		
Average body weight	670.3	666.5
Body weight gain (kg/day)	.40**	.15

[a] $\frac{\text{Current milk production}}{\text{Previous month milk production}} \times 100$

** Significantly (P<.01) different.

the treatments was observed. Both groups were equally persistent in milk production. Milk fat content did not change as a result of haylage feeding.

Average body weight of haylage-fed cows was 670.3 kg and hay-fed cows was 666.5 kg. The only beneficial effect of the whey-treated haylage was reflected in body weight gains of the cows. This difference in body weight gains of the whey group cows was significantly different ($P < .01$).

Higher in vitro dry matter and cellulose digestibilities (Table 4) were found in haylage than in hay. In the light of the previous experiment and other results (2), it seemed possible that whey-treated haylage had more digestible nutrients than did hay. In the present experiment the digestibilities of the chemical constituents other than cellulose and dry matter were not determined. Therefore, it was difficult to predict the relative digestibilities of other chemical constituents of haylage and hay. There are reports (88) indicating higher digestibilities of energy,

TABLE 4. In vitro dry matter and cellulose digestibilities of whey treated alfalfa haylage and hay.

	Group	
Measurement	Haylage	Hay
Dry matter digestibility (%)	54.0	48.8
Cellulose digestibility (%)	63.5	61.5

cellulose, dry matter, and protein in ration supplemented with lactic acid. The haylage fed to the cows had 6% lactic acid on dry matter basis. Lactic acid can replace 1.3 to 4.1 kg dry feed (20, 91). If this theory is true and completely applicable to the present study, then the benefits obtained in terms of body weight gain is attributed to the effects of dried whey which improved the fermentation of haylage and consequently improved the digestibilities of the chemical constituents of the haylage.

The results of the heifer growth trial are given in Table 5. The forage intake data indicated that heifers fed whey-treated haylages consumed slightly more forage dry matter than heifers fed hay (7.5 kg vs. 7.0 kg). Improved fermentation due to whey treatment may be associated with relatively higher haylage intake. This is in accord with the explanations offered by Zimmer and

TABLE 5. Response of dairy heifers fed hay and haylage.

Measurement	Group: Haylage	Group: Hay
Forage dry matter intake (kg/day)	7.5	7.0
Average body weight (kg)	314.4	286.9
Average daily gain (kg)	1.00*	.81
kg dry matter intake per kg body weight gain	7.54*	8.62

* Significantly ($P < .05$) different.

Kaufmann (198) and Wilkins et al. (186). As a result of intake of more digestible nutrients from haylage dairy heifers gained more ($P < .05$) body weight than did hay-fed heifers. Previous reports (160) indicate that hay-fed heifers had a higher rate of growth and voluntary intake than contemporary heifers fed untreated silage. The haylage fed to the heifers in the current trial was treated with whey. As the whey-treated haylage significantly ($P < .05$) increased the body weight gain of the heifers than did accompanying hay, the beneficial effect of haylage seemed to come from whey which produced desirable fermentation in alfalfa haylage. The feed efficiency was greater ($P < .05$) for whey treated haylage, probably on the same ground.

Experiment No. 3

PRESERVATION AND FEEDING VALUE OF ALFALFA HAYLAGE TREATED WITH OR WITHOUT WHEY

Introduction

The use of low-moisture silage or haylage in dairy cattle rations has been rapidly increasing on dairy farms. There are several reasons for the shift to haylage. Trials at USDA (63, 67) and at South Dakota (171) have shown the feeding value of haylage to be equal or superior to that of good quality hay.

The preservation of alfalfa sometimes presents a problem due to its high protein content and low sugar level. Reduction of moisture content has helped to produce good quality silage under suitable conditions of farm practices. But the need for supplemental carbohydrate to assure desirable fermentation still remains (36, 117, 177). This is especially true under usual farm conditions where storage conditions (anaerobiosis) and the moisture level of the crop are not optimal. Therefore, much of the effort to improve fermentation has been directed toward providing a more effective acidity and toward controlling fermentation by various means to minimize production of undesirable end-products. Thus, the use of additives has been primarily for the purpose of regulating microbial activity and to assure desirable fermentation.

Previous studies at this station have shown that addition of whey to alfalfa haylage has improved its fermentation and acceptability (45). This study was initiated (a) to determine the effect of dried whey on chemical composition of alfalfa haylage; (b) to determine the relative feeding value of this haylage compared to untreated haylage; and (c) to determine the changes in ruminal volatile fatty acid (VFA) production.

Experimental Procedures

In 1972, first-growth alfalfa was cut three weeks later than the usual cutting date due to unfavorable weather conditions. The alfalfa was in late bloom stage and was mature and stemmy when cut. It was dried to about 40% moisture, chopped finely (about 1 cm chop length), and blown to an oxygen-controlled silo. The same material treated with 2% dried whey (on dry matter basis) was ensiled in another oxygen-controlled silo. The forages were preserved for about six weeks before the onset of trials.

Lactation trial: Twenty lactating Holstein cows were divided as uniformly as possible into two groups by placing them in pairs on the basis of milk yield, stage of lactation, age, and body weight. Cows from each pair were randomly assigned to one of the two haylage treatments. Experimental haylages were fed ad libitum as the only roughage and were evaluated in a 12-week continuous trial following a 3-week adjustment period. The same concentrate mix was fed to both groups. The composition and chemical analyses are shown in Table 1. Both haylages and the concentrate mix were group-fed, and the feeding and management were similar during the entire period of the trial. The concentrate mix was fed at the rate of 1 kg/2.55 kg

TABLE 1. Percent composition and average chemical analyses of concentrate mix fed to cows.

	(%)
Ingredients	
Rolled corn	53.80
Rolled oats	35.69
Soybean meal (50% C.P)	7.89
Trace mineral salt	1.31
Dicalcium phosphate	1.31
Chemical composition	
Dry matter	88.6
Crude protein	13.4
Ether extract	3.8
Acid-detergent fiber	9.7
Ash	3.6

The concentrate mix contained 4,400 IU vitamin A/kg and 660 IU vitamin D/kg.

milk and was readjusted each week based on the previous weeks' production.

Haylages and the concentrate mix were sampled every week at the time they were fed. Haylage refusals were sampled weekly during each comparison period. All samples were frozen for later chemical analyses.

Daily milk weights were recorded for all cows. Once weekly, a 24-hour milk sample was analyzed for milk fat, total solids, and milk protein by AOAC methods (8).

Rumen fluid samples were collected during weeks 4, 8, and 12 of the experimental period via a suction strainer apparatus (132) four hours after the morning feeding. The pH of the rumen fluid was determined immediately using a glass electrode pH meter. Rumen fluid samples were preserved with 25% metaphosphoric acid (53) for later total and individual VFA analyses. Volatile fatty acids were analyzed as the free fatty acids by gas-liquid chromatography (15) using a stainless steel column (3.2 mm OD by 152. cm) containing 20% neopentylglycol succinate[1].

Body weights of all cows were taken three consecutive days at the beginning of the trial, then once every week, and three consecutive days at the end of the lactation trial. All chemical analyses except fiber constituents of feeds were conducted on oven-dried samples (48 C for 48 hr) by the AOAC methods (8).

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[1]Applied Science Laboratories, Inc., State College, PA.

Cell wall, acid-detergent fiber (ADF) and lignin were determined by the Van Soest system of feed analyses (58). Hemicellulose content was calculated as the difference between cell wall and ADF (58). Energy values were determined using a Parr oxygen adiabatic bomb calorimeter.

Digestion trial: Four Holstein steers weighing about 180 kg were fed the experimental haylages in a 5-day total collection period digestion trial as suggested by Hatten and Owen(73). This digestion trial was conducted concurrently with the lactation trial using the same haylages as the only feed source. Daily feed intakes and feces outputs were weighed and sampled. Duplicate samples of feed and feces were dried (48 C for 48 hrs) using a forced air oven and chemically analyzed as described above.

Haylages were sampled daily for 5 days during the collection periods of digestion trial. Silage extracts were prepared as described by Rumsey (134) and pH was determined with a conventional glass electrode pH meter. In an air-tight one pint mason jar, 100 g of alfalfa haylage was mixed with 60 ml of distilled water by thorough shaking. The jar was refrigerated at 4 C for 24 hr. The material was squeezed by a Carver Laboratory Press[1] to obtain the extract. A portion of the extract was deproteinized (134) for determination of VFA by gas-liquid chromatography as described by Baumgardt (15) and lactic acid by the methods of Langlois (94).

[1]Fred S. Carver, Inc., Summit, New Jersey.

All the data of lactation and digestion trials were analyzed by analysis of variance procedures as described by Steel and Torrie (150).

Results and Discussion

Haylages were evaluated for chemical quality on the basis of pH, and organic acids. Fermentation characteristics of the whey-treated alfalfa haylages showed (Table 2) a general pattern of superior quality over untreated alfalfa haylages. Whey-treated haylages had higher lactic acid ($P<.05$) and acetic acid ($P<.01$) than in untreated haylages. The acetic acid at this lower level has no undesirable effect on silage quality. The pH appeared to be reduced due to whey treatment, however, this decrease was not statistically significant. Both haylages were without any

TABLE 2. Fermentation characteristics of alfalfa haylages fed to dairy steers and Holstein cows.

Items	0% Whey haylage	2% Whey haylage	Standard error
pH	4.70	4.24 NS	$\pm.16$
Lactic acid (%)	3.98	8.02*	$\pm.94$
Acetic acid (%)	.42	.92**	$\pm.04$

NS Not significant ($P<.05$)

* Significant ($P<.05$)

** Significant ($P<.01$)

butyric acid which is considered as a good indicator of high quality haylage. It is generally agreed that good quality silage is characterized by a low pH, low contents of butyric acid and acetic acid, and high levels of lactic acid (13, 95, 177).

Results of chemical analyses of the haylages are presented in Table 3. The dry matter content of whey-treated haylage was slightly higher than that of untreated haylage. This increase in dry matter content may have been partially due to the added dry matter from whey. Energy values were similar for both types of haylages. Whey treated haylage had slightly lower contents of cell wall, ADF, cellulose, and was higher in ash content. These differences were probably due to the dilution effect of whey.

A summary of the mean apparent digestion coefficients is given in Table 4. Apparent digestibilities of dry matter, energy, crude protein, ash, cell wall, ADF, and cellulose were greater ($P<.01$) for the whey-treated haylage. Similar ether extract digestibility coefficients for both types of haylages were obtained. Although the lignin and hemicellulose digestibilities were slightly higher for whey-treated haylage, they were not significantly different. The digestibility data indicated that whey-treated haylage contained more digestible nutrients than the untreated ones. Improved digestibility with improved fermentation of silages treated with various additives have been reported by several workers (2, 177). Improved feeding value of high lactic acid silage (90, 91) and increased digestibilities of energy, dry matter, cellulose, and protein of

TABLE 3. Average chemical composition of alfalfa haylages fed to dairy steers and Holstein cows.

Items	0% Whey haylage	2% Whey haylage
Dry matter (%)	56.60	60.60
Energy[a] (K cal/g)	4.31	4.30
Crude protein[a] (%)	16.28	16.67
Ether extract[a] (%)	2.49	2.44
Ash[a] (%)	6.80	7.19
Cell wall[a] (%)	47.06	46.21
Acid-detergent fiber[a] (ADF) %	41.61	40.78
Lignin[a] (%)	8.52	8.23
Cellulose[a] (%)	33.09	32.55
Hemicellulose[a] (%)	5.45	5.43

[a]On dry matter basis.

TABLE 4. Digestibility of alfalfa haylages fed to dairy steers.

Items	0% Whey haylage	2% Whey haylage	Standard error
	Digestion coefficient		
Dry matter	60.3	66.3**	±.79
Energy	58.9	64.3**	±.99
Crude protein	63.3	68.8**	±.68
Ether extract	67.1	67.5NS	±.81
Ash	38.2	53.4**	±1.32
Cell wall	53.8	59.8**	±.72
Acid-detergent fiber (ADF)	54.8	61.6**	±1.12
Lignin	27.0	34.7NS	±2.72
Cellulose	61.7	68.3**	±.84
Hemicellulose	45.7	46.9NS	±3.82

** Significantly ($P < .01$) different.

NS Not significant ($P < .05$).

rations supplemented with lactic acid have also been reported (88).

Feed consumption, milk production, persistency, milk composition, and body weight values are presented in Table 5. The voluntary forage consumption was higher from whey-treated haylage than from untreated haylage. The concentrate consumption was lower for cows in whey treated haylage group (whey group). However, this lower intake was due to lower amount offered on the basis of milk production. The higher intake of whey-treated haylage by the cows in the whey group may be due to lower amount of concentrates fed. However, several workers (186, 198) have indicated that higher intake of silages is associated with improved fermentation. Improved fermentation in whey-treated haylage may be responsible for higher haylage intake (149).

Milk production and composition were similar for cows on both treatment groups. When milk yield was converted to a 4% fat-corrected milk (FCM) basis, cows fed untreated haylage produced slightly higher FCM than cows fed treated haylage. However, this difference was not significantly different between the treatments. Cows fed whey-treated haylage were less ($P < .05$) persistent than the cows fed untreated haylages. The persistency of milk production was calculated by comparing the current weeks' production with that of the corresponding week of the previous month. In this way persistency of milk production was calculated from the fifth week of the trial and first 4 weeks production could not be accounted for. Probably this was the reason why there was a significant

TABLE 5. Average response of cows fed alfalfa haylage treated with or without whey.

Response	0% Whey haylage	2% Whey haylage	Standard error
Dry matter intake (kg/day)			
Haylage	12.67	13.67	± .28
Concentrate	7.62	7.29	± .06
Total	20.29	20.96	
Milk production (kg/day)			
Actual milk	18.84	17.94	±1.04
4% Fat-corrected milk	18.14	16.91	±1.05
Persistency	90.69	85.88*	±1.42
(current production / previous month production x 100)			
Milk composition (%)			
Fat	3.75	3.62	± .14
Total solids	12.66	12.53	± .23
Protein	3.31	3.43	± .07
Body weight (kg)			
Average weight	632.31	649.60	±21.40
Body weight change (End-Start)	15.18	45.51**	±5.27

* Significantly ($P < .05$) different.

** Significantly ($P < .01$) different.

difference between persistencies of milk production when there was no difference in milk production between the treatments.

Absence of response from whey-treated haylage on milk yield can not be adequately explained, although some contributing factors may be suggested. The digestibility values obtained by feeding haylages to dairy steers may not be directly applied to the lactating cows. The cows were fed haylages ad libitum with calculated amounts of concentrates whereas the steers were fed only haylages as the sole ration at restricted levels. The associative effect of roughage and concentrates perpetuate the problem of predicting accurate digestibility. Putnam and Loosli (130); Barnett (14); Conrad and Hibbs (41); Conrad et al. (42, 43) and Terry et al. (157) have reported that ruminant animals can digest the structural carbohydrates of forages to a greater degree when these materials are fed alone than when they are fed mixed with supplements of grain.

In the current trial, the rumen pH was 6.1 for both treatment groups and possibly this reduced fiber digestibility. Terry et al. (157) have shown that fiber digestibility is highest at rumen pH of 6.8 and is depressed markedly as the pH is reduced. The lower rumen pH is associated with combined grain and roughage feeding, and this substantiates the idea that cows in the current lactation trial receiving both grain and roughage might have shown depressed fiber digestion.

The only beneficial effect obtained from whey-treated haylage as a result of higher digestibility was body weight gain which

TABLE 6. Ration effects on rumen pH and volatile fatty acids (VFA).

Measurement	0% Whey haylage	2% Whey haylage	Standard error
pH	6.10	6.10	± .05
Rumen VFA (molar %)			
Acetic	69.75	69.77	± .59
Propionic	16.88	17.06	± .41
Isobutyric	.56	.55	± .05
Butyric	11.40	11.16	± .38
Isovaleric	.85	.85	± .09
Valeric	.55	.52	± .06
Total VFA (μM/ml)	68.27	68.62	±2.06
Acetic/Propionic	4.13	4.14	± .12

was significantly higher ($P < .01$) than that for the cows fed untreated haylages. The cows in the present trial were in late lactation and gained more weight when fed whey treated haylages. Fattening and body weight gain during later part of lactation is desirable as it builds up body reserve of energy (112).

Rumen VFA values (Table 6) reveal no significant differences when expressed as molar percentages of total VFA in rumen fluids. Rumen pH, total VFA (μM/ ml) and acetate to propionate ratio were similar for both treatments.

Experiment No. 4

COMPARISON BETWEEN WHEY AND LACTOSE AS ALFALFA HAYLAGE PRESERVATIVE

Introduction

Adding whey to alfalfa haylage at ensiling has improved its quality by increasing lactic acid concentration, decreasing butyric acid content and by reducing pH (45, 120). The main reason for considering whey as a silage additive is to utilize its lactose as a source of readily available carbohydrate for lactic acid production. There are virtually no reports available to give a comparative evaluation of whey and lactose as silage additives. Early work of Salisbury et al. (136) indicated that mixed cultures of silage organisms when offered various carbohydrate sources like arabinose, glucose, sucrose, fructose, and xylose resulted in faster and relatively higher acid production, thus producing desirable silage fermentation. Lactose was found comparatively less efficient in acid production. In their opinions, this factor is responsible for the unsuitability of whey as a silage additive. Against their views, however, Archibald (5) and Nevens and Kuhlman (120) demonstrated that dried whey was more efficient than molasses in stimulating lactic acid production in silages. Later reports of Barnett (13) and Watson and Nash (177) confirmed the opinions of Archibald (5) and Nevens and Kuhlman (120).

This experiment was designed to determine the relative effectiveness of lactose compared to whey as a silage preservative. A comparison of treated and untreated haylages with hay (from same source) has been included in this experiment also.

Experimental Procedures

First growth alfalfa was cut for haylages at late full-bloom stage. The forage was dried to about 60% dry matter, chopped by a mechanical harvester set at approximately 1 cm chop length, and stored in different silos with or without treatments. Some of these materials were stored in an oxygen-limited silo and the other contained 2% dried whole whey when preserved in another oxygen-limited silo. Materials from the same source at the same dry matter contents were treated with 0, 1.4, and 7% lactose and preserved in sealed metal containers. Hay from the same source was reserved for later study. The treatment levels containing 0 and 1.4% lactose corresponded to the relative amounts of lactose in the dried whey used in the present study. Lactose was used at the 7% level in the haylages because of the use of whey at the 10% level in the previous studies reported in this thesis. The haylages were preserved for 6 weeks before the onset of the trial.

Four Holstein steers, initially weighing 175 to 200 kg, were fed experimental haylages and hay ad libitum and restricted to maintenance in a 5-day total collection period digestion trial as suggested by Hatten and Owen (73). The haylages and hay were the only feed source for the steers. Daily total feed intakes and fecal outputs of the individual steers were weighed and duplicate samples of feed and feces were dried in a forced draft oven at 40 C for 48 hours. Chemical analyses were conducted by the following procedures: Crude protein was determined by Kjeldahl method (8), ether extract and ash by the AOAC methods (8). Dry matter was determined using a forced draft oven (100 C for 48 hours). Energy values were determined using a Parr oxygen adiabatic bomb calorimeter. Cell wall, acid-detergent fiber (ADF), and permanganate lignin were determined by the procedures suggested by Goering and Van Soest (58). Cellulose contents of the feed and feces were calculated by subtracting the percent lignin from the percent ADF (58). Hemicellulose in feed and feces was estimated as the difference between cell wall and ADF (58, 166).

Duplicate samples of haylages were taken every day during the collection periods of the digestion trial. Haylage extracts were prepared as suggested by Rumsey (134) and pH was determined with a conventional glass electrode pH meter. A different extraction procedure was followed for lactic acid and VFA determinations. Alfalfa haylage weighing exactly 100 g was treated with 60 ml of distilled water in an air-tight one-pint glass jar. The material was well mixed with water by thorough shaking. The jar was refrigerated at 4 C for 24 hours before it was squeezed by a Carver Laboratory Press[1] to obtain the haylage extract. A portion of the

[1]Fred S. Carver Inc., Summit, New Jersey.

extract was deproteinized (134) for determination of volatile fatty acid (VFA) by gas-liquid chromatography as described by Baumgardt (15), and lactic acid by the methods of Langlois (94).

Rumen fluid samples of the steers were collected during days 3, 4, and 5 of each collection periods of the digestion trial using a suction strainer apparatus (132) 3 hours post morning feeding. Each rumen fluid sample was treated with .5 ml of saturated mercuric chloride solution, strained through four layers of cheese cloth, deproteinized with 25% metaphosphoric acid (53), and frozen until analyzed for total and individual VFA by gas-liquid chromatography (15).

The data from this trial were subjected to analysis of variance by the procedures described by Steel and Torrie (150). When significant differences were obtained for a given set of data, orthogonal comparisons were used to determine significant differences between treatment means. Correlation analyses were performed according to Steel and Torrie (150) to determine if there were any relationships between intakes and digestibilities of the feed constituents.

Results and Discussion

A summary of the average pH value, lactic acid content and acetic acid content of haylages are given in Table 1. The pH values ranged from 4.24 to 4.74. Haylages with 0, 1.4, and 7% lactose were preserved in sealed metal containers while 0 and 2% whey silages were preserved in oxygen-limited silos. The pH values for 0% and

TABLE 1. Fermentation characteristics of alfalfa haylages.

Haylage treatments	pH	Lactic acid	Acetic acid
		(% in dry matter)	
0% Lactose	4.74	4.78	.49
1.4% Lactose	4.34	7.00	.69
7% Lactose	4.56	6.10	.44
0% Whey	4.70	3.98	.42
2% Whey	4.24	8.02	.92
Standard error	±.15	±.65	±.04
Probability			
0% Lactose vs. 0% Whey	NS	NS	NS
0% Lactose and 0% Whey vs. 1.4% Lactose, 7% Lactose and 2% Whey	<.05	<.01	<.01
1.4% Lactose vs. 2% Whey	NS	NS	<.01
1.4% Lactose and 2% Whey vs. 7% Lactose	NS	NS	<.01

1.4% lactose haylages were similar to the corresponding haylages treated with 0% and 2% whey. Treated haylages had significantly lower ($P<.05$) pH values than that of untreated haylages. Haylages treated with 7% lactose did not show an advantage in reducing pH. It seems that lactose is more effective at the lower level than at the higher level. Lactic acid concentrations in the haylages followed a reverse trend as pH. Here again, 7% lactose haylage had rather lower lactic acid content than that of 1.4% lactose haylage and 2% whey haylage. Acetic acid concentrations in all haylages were below 1%. Significant differences between the treatments at these lower levels of acetic acid have no practical value. In general, the fermentation characteristics indicated that good quality haylages can be made using lower levels of either whey or lactose. Fermentation results further suggest that lactose is as efficient as whey in stimulating lactic acid production. This view contradicts the conclusions of Salisbury (136) that lactose is inefficient in producing an acid type of fermentation and supports the conclusions of Barnett (13) and Watson and Nash (177), who advocated that whey is an effective silage preservative due to its high lactose content.

Absence of butyric acid, low contents of acetic acid, high contents of lactic acid, and reduced pH values indicated that the experimental haylages were of good quality. Similar views have been expressed for silage quality (63, 95).

TABLE 2. Chemical constituents of alfalfa haylages and hay fed to dairy steers.

Treatments	Dry matter	Energy	Crude protein	Ether extract	Ash	Cell wall	Acid-detergent fiber	Cellulose	Lignin	Hemicellulose
Haylage treatments	(%)	(K cal/g)	(% of dry matter)							
0% Lactose	61.1	4.16	16.8	2.41	7.9	48.1	41.4	34.3	7.1	6.7
1.4% Lactose	60.4	4.12	15.8	2.45	7.7	47.5	40.9	34.4	6.5	6.6
7% Lactose	63.7	4.13	15.3	2.41	6.8	45.1	37.1	30.3	6.8	8.0
0% Whey	56.6	4.31	16.3	2.49	6.8	47.1	41.6	33.1	8.5	5.5
2% Whey	60.6	4.30	16.7	2.44	7.2	46.2	40.8	32.6	8.2	5.4
Hay	84.8	4.18	14.4	2.01	6.9	56.9	44.5	35.4	9.1	12.4

Chemical constituents of the haylages and hay are presented in Table 2. Dry matter contents of haylages indicated that preservatives had no influence on dry matter content of haylages. The higher dry matter content of 7% lactose haylage may be due to the added dry matter from lactose. Energy values were similar for all haylages treated with lactose whereas haylages preserved in oxygen-limited silos with or without whey treatment showed slightly higher energy value. This may be due to the better method of preservation. Haylages had similar crude protein values, but they were comparatively higher than corresponding protein content of hay. Ether extract values of haylages were slightly higher than that of hay because of the organic acids in the haylages (18). Ash contents were similar for hay and haylages. The cell wall content of hay was a simple reflection of its quality. The hay was made from stemmy mature alfalfa which was in late full-bloom stage. Mature, stemmy forage plants usually show higher proportions of cell wall constituents (153, 167). Haylages in general had lower cell wall contents than corresponding hay. These differences in cell wall contents of hay and haylages were more clearly expressed in hemicellulose and cellulose fractions. The differences of ADF values of hay and haylages were primarily due to cellulose. The chemical composition of haylages and hay clearly suggested that greater amounts of hemicellulose and lesser amounts of cellulose had been utilized in the fermentation process, probably for the production of organic acids. McDonald et al. (104, 105, 106), Zimmer (197),

TABLE 3. Digestibilities of various alfalfa haylages and hay fed to dairy steers.

Treatments	Dry matter	Energy	Crude protein	Ether extract	Ash	Cell wall	Acid-detergent fiber	Cellulose	Lignin	Hemi-cellulose
Haylage treatments	(%)									
0% Lactose	59.7	57.5	68.7	63.1	37.2	52.7	51.9	57.4	25.2	56.3
1.4% Lactose	62.9	61.8	70.8	68.7	47.9	56.6	57.2	62.5	29.2	54.7
7% Lactose	68.1	67.6	72.5	71.8	54.2	61.1	59.7	64.6	38.7	67.7
0% Whey	60.3	58.9	63.3	67.1	38.2	53.8	54.8	61.7	27.0	45.7
2% Whey	66.3	64.3	68.8	67.5	53.4	59.8	61.6	68.3	34.7	46.9
Hay	57.2	52.9	63.1	47.2	31.0	49.8	50.8	60.2	14.2	46.7
Standard error	±.90	±.96	±.91	±1.00	±1.31	±.88	±1.20	±1.18	±2.44	±3.44
Probability										
0% Lactose vs. 0% Whey	NS	NS	<.01	<.05	NS	NS	NS	<.05	NS	<.05
Hay vs. 0% Lactose and 0% Whey	<.05	<.01	<.05	<.01	<.01	<.01	NS	NS	<.01	NS
0% Lactose, 0% Whey, and hay vs. 1.4% Lactose, 7% Lactose, and 2% Whey	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.01	<.05
1.4% Lactose vs. 2% Whey	<.05	NS	NS	NS	<.01	<.05	<.05	<.01	NS	NS
1.4% Lactose and 2% Whey vs. 7% Lactose	<.01	<.01	<.05	<.01	<.05	<.05	NS	NS	<.05	<.01

and De Man (46) have reported the utilization of cell wall constituents for production of organic acids. Some of the differences in cellulose and hemicellulose contents of the treated haylages were attributed to the dilution effects of respective lactose and whey.

A summary of the average apparent digestion coefficients is given in Table 3. Results of the dry matter digestibilities showed a clear advantage for haylage in general over corresponding hay. Treated haylages had more ($P < .01$) digestible dry matter than the untreated haylages and hay. Whey improved ($P < .05$) dry matter digestibility of haylage more than lactose did when a comparison of 1.4% lactose versus 2% whey haylage was made. This indicates that whey components, other than lactose, have some contributing effects in improving dry matter digestibility of haylages. Haylage treated with 7% lactose showed its superiority over other haylages and hay. This difference in dry matter digestibility in treated haylages may not be fully attributed to the dilution effect of whey or lactose. Energy digestibility followed the same trend as dry matter digestibility did except that 2% whey-treated haylage had similar energy digestibility as 1.4% lactose-treated haylage did. This suggested that lactose and whey were probably comparable in improving energy digestibility of haylages. Haylages without any treatment preserved in metal containers showed improved protein digestibility over the corresponding untreated haylage preserved in an oxygen-limited silo. No explanation for the difference in protein digestibility can be offered.

The digestibility co efficient for protein was lower for hay than for untreated haylages. This supports the results reported by Thomas et al. (160). If the higher digestibility of protein is assumed due to improved fermentation of silage or haylage, then the additives which can improve the silage fermentation can improve the digestibility of protein. Treated haylages showed higher protein digestibility than the untreated ones. Haylage treated with 7% lactose had more ($P < .05$) digestible protein than 1.4% lactose and 2% whey treated haylages.

Ether extract digestibility of the forages ranged from 47.2% to 71.8%, lowest was for hay and highest was for 7% lactose-treated haylage. The significantly lower ($P < .01$) ether extract digestibility of hay than that of untreated haylage observed in the current experiment is in agreement with the results reported by other workers (63, 160). Digestibility of ash ranged from 31.0% to 53.4%. Ash was least digestible in hay and most digestible in 7% lactose-treated haylage. Haylage treated with 2% whey had higher ash digestibility than corresponding haylages treated with 1.4% lactose. Whey constituents other than lactose may be responsible for this improved ash digestibility.

Cell wall digestibility of hay was 49.8% and this was lower ($P < .01$) than the corresponding untreated haylages. The digestibility coefficients for ADF, cellulose, and hemicellulose were similar for hay and untreated haylages, except that lignin digestibility was significantly lower ($P < .01$) for hay than for untreated haylages. The lower digestibility of lignin of hay appeared to be associated with the lower digestibilities of other cell wall constituents. When the digestibility coefficients of the cell wall constituents were compared, the untreated haylages preserved in metal containers were found to have similar digestibility coefficients for cell wall, ADF, and lignin, to those of the untreated haylage preserved in oxygen-limited silos. Cellulose was more digestible in 0% whey haylage than in 0% lactose haylage. On the contrary, the hemicellulose digestibility was just opposite to that of cellulose digestibility in these haylages. This may be the probable reason why this was not reflected in cell wall digestibility. In general, fiber components were more digestible in treated haylages than in untreated haylages and hay. Cellulose was more digestible ($P < .01$) when alfalfa was treated with 2% whey than the haylage treated with 1.4% of lactose. The higher cellulose digestibility for 2% whey-treated haylage seemed to account for its higher digestibilities of cell wall and ADF. Lactose added to haylage at the 7% level improved the digestibilities of hemicellulose, lignin and cell wall significantly more than that of 2% whey and 1.4% lactose treated haylages.

The digestion of the three major cell wall constituents, such as cellulose, hemicellulose, and lignin, may be considered together. The decline in digestibilities of these cell wall constituents of hay and haylage in the present study was possibly due to the increasing maturity of the forage which also corresponded to the lower dry matter digestibility of the forage. Similar views on the digestibilities of cell wall constituents have been expressed by Allison and Osbourn (3). The digestibility of lignin is of great importance. Estimates of lignin digestibility vary widely, though commonly the lignin complex is assumed to be indigestible (153, 173). Correcting crude lignin values for nitrogen content gives varying results, frequently increasing estimates of lignin digestibility (10,52). Delignification increases the digestibility of cellulose (3). The importance of the type of cellulose-lignin complex has been indicated by Sullivan (153) who demonstrated that the capacity of rumen organisms to attack degraded cellulose was no criterion of its availability to attack undegraded types of cellulose. There are chemical bonds linking lignin to hemicellulose (22) and lignin to cellulose, and perhaps lignin to cell wall protein (153). When such links between lignin and cellulose and lignin and hemicellulose exist, lower digestibilities of cellulose and hemicellulose are obtained. Gordon and Homes (60) divided lignin into two fractions, core lignin which consists of phenolic monomers linked mainly by ether and carbon to carbon bonds, and non-core lignin consists mainly of ferulic and p-coumaric acids linked to core lignin by ester bonds. These bonds are easily broken by alkali and may also be hydrolyzed in the digestive tract, in which case some digestion of lignin can occur. Some workers (111, 116, 160, 173) have reported digestion coefficients of lignin from as high as 42% to negative values.

TABLE 4. Volatile fatty acids (VFA) in rumen fluid of dairy steers fed different alfalfa haylages and hay.

Treatments	Total VFA µM/ ml	Molar percent: Acetic	Propionic	Isobutyric	Butyric	Isovaleric	Valeric	Acetate/ Proprionate
Haylage treatments								
0% Lactose	51.60	79.44	18.95	.06	1.53	-	-	4.27
1.4% Lactose	63.57	78.63	17.51	.15	3.57	.13	-	4.51
7% Lactose	78.24	72.76	20.80	.16	7.29	.19	-	3.50
0% Whey	64.27	71.32	21.23	.77	6.05	.61	-	3.36
2% Whey	60.31	69.26	20.71	.82	8.06	.70	.45	3.36
Hay	48.99	75.24	17.95	.81	5.59	.22	.18	4.19
Standard error	±3.20	±.95	±.68	±.07	±.35	±.06	±.04	±.18
Probability								
0% Lactose vs. 0% Whey	<.05	<.01	<.05	<.01	<.01	<.01	NS	<.01
Hay vs. 0% Lactose and 0% Whey	.05	NS	<.05	<.01	<.01	NS	<.01	NS
0% Lactose, 0% Whey and Hay vs. 1.4% Lactose, 7% Lactose and 2% Whey	<.01	<.05	NS	<.05	<.01	NS	<.05	NS
1.4% Lactose vs. 2% Whey	NS	<.01	<.01	<.01	<.01	<.01	<.01	<.01
1.4% Lactose and 2% Whey vs. 7% Lactose	<.01	NS	NS	<.01	<.01	<.01	<.01	NS

When superiority of silage over its corresponding hay is considered, its organic acids are said to improve silage digestibility (152). High content of lactic acid in the silage may be the cause of higher digestibility of silage over hay (129). Johnson et al. (88) reported higher digestibility of energy, dry matter, cellulose and protein of rations when supplemented with lactic acid. Klosterman et al. (90, 91) reported higher feeding value of silages with higher concentrations of lactic acid than the corresponding low-lactic acid silage. The work of Sutton and Vetter (154) indicated that improved fermentation is responsible for improved cellulose digestibility. Higher digestibilities of chemical constituents of whey-treated silage over that of corresponding untreated silage (2) suggest that improvement in silage fermentation may probably increase the digestibilities of chemical constituents including cell wall components. The improved digestibilities of several chemical constituents of the haylages was attributed to the improved fermentation by whey or lactose. The improved fermentation was also considered mainly by amount of lactic acid produced. Whey constituents other than lactose appear to be partly responsible for improved digestibility of haylages.

Total VFA (μm/ml) and molar percent of individual VFA are given in Table 4 along with standard error of mean and statistical analyses. Total VFA concentrations in rumen fluids tended to be lower, acetate and isovalerate similar, propionate lower, isobutyrate and butyrate higher, in steers fed hay than in those fed haylage diets. Untreated haylage preserved in oxygen-controlled silos resulted in higher production of rumen VFA (total and individual) than the corresponding untreated haylage preserved in metal containers. Acetate to propionate ratio was significantly lower ($P < .01$) in 0% whey treatment than in 0% lactose treatment. Haylage treated with 1.4% lactose tended to produce more total VFA than the 2% whey-treated haylage. However, this difference was not statistically significant. When compared with 1.4% lactose-treated haylage, 2% whey-treated haylage showed a significant reduction in molar percent of acetic acid ($P < .01$), significant increase in propionic acid, isobutyric acid, butyric acid, isovaleric acid and valeric acid, and lower acetic to propionic acid ratio. There was a significant increase ($P < .01$) of total VFA due to 7% lactose haylage feeding. The molar percent of butyric acid for 7% lactose haylage diet was higher than 1.4% lactose haylage diet but lower than 2% whey haylage diet.

It appeared from the analysis of rumen fluid that haylages were better than hay in increasing the total VFA concentration when fed to steers. Similar results have been obtained when cows were fed hay and silage (133). It has been reported that the amount and type of ration influence the ruminal pH and VFA concentration (34, 135, 158). The effectiveness of 7% lactose-treated haylage in producing higher concentrations of total VFA was attributed to the effect of lactose. Inconsistent treatment effects were noted on percentages of individual rumen VFA and the acetate to propionate ratio. Lower molar percentage of butyrate in some treatments may be presumed to be due to interconversions of butyrate to acetate. Lower molar percent of butyrate and higher molar percent of acetate have been associated with wider acetate to propionate ratio. Interconversion of butyrate to acetate in the rumen is possible (100).

Experiment No. 5

EVALUATION OF DRIED WHEY AS A GRAIN SUPPLEMENT FOR DAIRY COWS

Introduction

There is a great deal of interest to recycle whey through the cows that produce it (16, 62, 81, 83, 179). Recent studies (81, 83, 140) indicated that adding whey to restricted-roughage rations of cows producing abnormally low-fat milk caused milk fat production to return towards normal.

Adding whey to grain rations of cows receiving roughage ad libitum, and therefore rations which are not fat depressing, may also stimulate milk fat production and/or milk production. Bishop and Bath (21) found that such rations caused a slight increase in fat percent, but this was offset by a decline in milk yield.

This experiment was conducted to evaluate feeding dried whey as a grain supplement for dairy cows when roughage is provided ad libitum. Supplementation of whey to a grain mix at the rate of 5% was done on the basis of the beneficial responses obtained from swine and beef cattle by feeding lower levels of whey (178, 191); further, feeding higher levels of whey in the concentrates may not be economically feasible.

Experimental Procedures

In a 13-week lactation trial twenty Holstein cows which were in late lactation, were assigned to two treatment groups balanced on the basis of milk production, fat percentage, and stage of lactation. Cows in control groups were fed the same concentrate mix that had been fed regularly to these cows prior to initiation of the trial. Cows in the whey group received the same amount of crude protein from a concentrate mix containing 5% dried whole whey. Ingredient composition of the concentrate mixes with approximate analyses are shown in Table 1. Both groups were offered identical corn silage and alfalfa hay ad libitum. All concentrates and roughages were group-fed to the cows housed in pens of 10 cows each. Concentrates were fed at the rate of 1 kg/2.5 kg milk production. Amounts fed were readjusted each week, based on previous weeks' production.

Core samples of hay, grab samples of silage, and samples of both concentrate mixes were taken every week for chemical analyses (Table 1 and 2). Daily feed consumption and milk production data of all cows were recorded. Daily composite milk samples were taken on alternate weeks and were analyzed for milk fat, total solids, and protein by Official Methods of Analysis (81). All cows were weighed on three consecutive days at the beginning of the experiment, then once every month, and three consecutive days at the end of the experiment. All the data were subjected to analyses of variance (150).

Results and Discussion

Average milk yields and composition data are in Table 3. Milk yields for the entire period were not significantly altered by whey supplementation, but tended towards lower fat correct milk (FCM)

TABLE 1. Ingredients and average analyses of concentrates fed.

	Control ration	Whey ration
	(%)	
Ingredients:		
Rolled shelled corn	51.25	46.60
Oats	34.00	34.00
Soybean meal (50% C.P.)	11.25	10.90
Urea	1.00	1.00
Dicalcium phosphate	1.25	1.25
Trace mineral salt	1.25	1.25
Dried whole whey	---	5.00
Analyses (% dry matter)		
Crude protein	16.8	16.8
Ether extract	3.9	3.7
Crude fiber	6.8	6.5
Ash	3.7	4.1

Both rations contained 4,400 IU Vitamin A/kg and 660 IU Vitamin D/kg.

TABLE 2. Average composition of forages fed (on dry basis).

	Dry Matter	Crude Protein	Ether Extract	Crude Fiber	Ash
	(%)				
Alfalfa hay	88.9	17.1	2.3	29.7	7.6
Corn silage	36.4	8.4	2.1	23.1	5.8

production for the whey-fed group. Persistency of milk yields was not affected by treatment. However, the differences in average milk production during the experiment is a simple reflection of the similar difference in pretreatment production. This is consistent with previous observations of other researchers (21, 81, 83, 140) that whey products commonly used to increase fat test usually result in a slight decrease in amount of milk produced.

Average milk fat percentages for both control and whey groups were 4.7% (Table 3). The average fat percent for the control group indicates that there was no depression of fat content due to the kind of ration fed during the period of this experiment. Probably when the fat content is high, it cannot be elevated further by whey treatment. In a recent report, Schingoethe et al. (140) noted a decline of milk fat content with demineralized whey, suggesting that whey minerals were important in maintaining milk fat production. In view of these reports (81, 83, 140), it seems that whey is beneficial to correct milk fat depression under conditions of fiber-restricted rations, but may be of no fat-stimulating

TABLE 3. Average milk yields and compositions of cows fed normal and whey supplemented rations.

Items	Control ration	Whey ration	Standard error
Milk yields (kg/day)	17.4	16.2	±2.07
4% Fat corrected milk	19.2	17.8	±2.19
Persistency[a]	87.8	87.5	±1.30
Fat (%)	4.7	4.7	±0.15
Fat production (kg/day)	.8	.8	±0.09
Total solids (%)	13.9	14.2	±0.23
Total solids production (kg/day)	2.4	2.3	±0.28
Protein (%)	3.8	4.0	±0.07
Protein production (kg/day)	.6	.6	±0.08

[a] $\frac{\text{current production}}{\text{previous month production}} \times 100$

benefit with normal rations. Milk protein and total solids percentages were not affected by adding whey to the concentrate mix. High energy rations increase protein concentration of milk (23, 24, 29, 82, 195). Probably at this low level whey could not change the energy value of the ration and did not influence the milk protein precursors to boost higher milk protein content.

Feed intake data and body weight figures are presented in Table 4. As mentioned in the experimental procedure, the cows were group-fed. Average weekly feed intake data, when subjected to statistical analyses, showed higher ($P<.01$) consumption of concentrates by control cows. This difference was expected, as the control cows had been fed higher concentrates than whey-fed cows because

TABLE 4. Average feed dry matter intakes and body weights of cows fed normal and whey-supplemented rations.

Items	Control ration	Whey ration
Concentrate intake (kg/day)	6.1	5.6
Alfalfa hay intake (kg/day)	3.3	3.4
Corn silage intake (kg/day)	12.0	12.7
Total dry matter intake (kg/day)	21.4	21.7
Body weight (kg)	695.4	672.3
DM intake (kg/100 kg BW)	3.1	3.2
Body weight gain (kg) (Final wt-initial wt)	37.8	48.9

of their higher milk production. Dry matter intakes of hay were not significantly influenced by whey. However, silage intake was higher ($P < .05$) for whey-fed cows. This higher intake of silage by whey-fed cows may be due to the lower allowance and consumption of concentrate. The total daily dry matter intakes for control and whey-fed cows were 21.4 kg and 21.7 kg, respectively. Although the whey-fed cows appeared to have gained slightly more body weight than the control cows, this difference was not statistically significant.

Cows involved in this experiment were in late lactation. Their milk production followed a declining trend, as usual. Dried whey at this low level did not demonstrate any noticeable advantage in terms of milk production, fat production or body weight gains. Further studies using early lactation cows with higher levels of production are necessary to fully evaluate the practice of feeding low levels of whey in concentrate rations.

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